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ABSTRACT

This study defines some of the educational ecosystems that encourage students to discover science interests and science talent. Six interrelated constructs are discussed. Construct 1 consists of a skein of achievement-centered, goal-targeted environments that comprise the inspiring teaching and learning that can enhance the endowments of students. Construct 2 presents studies of unfavorable environments that block the goals of equal opportunity, optimum achievement in science, and the discovery of science proneness or talent. Construct 3 involves elements of formal learning in augmenting environments, focusing on instruction as an event evoking early discovery through self-identification of gifted children with a particular bent to science. Construct 4 presents a curricular structure for facilitating augmenting environments and a system for discovery and self-selection of all students for differentiated, sustainable futures in today's postindustrial world. Construct 5 suggests a mode by which students identify and select themselves to participate in differentiated programs of demanding study culminating in long-term originative inquiry. Construct 6 discusses science talent in practice and provides an operational definition of science talent. An executive summary is provided. Appendices include a list of effective science programs for students grades K-12 and a sample structure for science in elementary schools. (Contains approximately 280 references.) (Author/CR)

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Consultant in Science and Education
Unionville, New York

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About the Author...

As a research biologist, **Paul F. Brandwein**, Ph.D., probed the host-parasite relationship of plant pathogens. He taught in various universities and later turned to schooling. Early, as chair at Forest Hills High School (New York), he directed and taught in its science talent program in originative inquiry.

He was Burton Lecturer at Harvard, Abbot Lecturer at Colorado College, Urban Scholar at the University of Houston, and director of education at the Conservation Foundation (Washington, D.C.). While co-director of the Pinchot Institute for Conservation Studies (Milford, Pennsylvania), he was also adjunct professor at Pittsburgh University.

He served on the Steering Committee of the Biological Sciences Curriculum Study (BSCS), as chair of its Gifted Student Committee, as consultant to the Physical Science Study Committee (PSSC). Both committees developed programs of originative inquiry designed to interest high school students in science. He continued his work as an author and international consultant in science education until his death.

Before and during the development of curriculums and instructional materials, he turned to publishing. He became president of Harcourt Brace Jovanovich's Center for the Study of Instruction (San Francisco) and its director of Research in Curriculum and Instruction; later, he was director and editor in chief of the School Division; finally, he was co-publisher of Research-Based Publications.

Dr. Brandwein was author and coauthor of some 50 books and studies, numerous research papers in science and science education, particularly in relation to the science shy, the science prone, the science talented, and the humanities. His biography appears in *American Men and Women in Science* and *Who's Who in the Humanities*. He was a member of Phi Beta Kappa, Sigma Xi, the New York Academy of Sciences, and a fellow of the American Association for the Advancement of Science. His awards included several honorary degrees and a number of citations and honors from organizations devoted to science, the humanities, and teaching.

When he died on September 15, 1994, Dr. Brandwein had completed an expanded version of this volume. The revised and shortened edition presented here was nearly ready for publication. It was edited by Evelyn L. Morholt, Ed.D., and Deborah C. Fort, Ph.D., who had been working with him on the manuscript. They take responsibility for any errors Dr. Brandwein would have corrected, had he been able to give the manuscript a last careful reading.

The wisdom is his.

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Science Talent in the Young Expressed Within Ecologies of Achievement

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ABSTRACT

Six interrelated constructs form the body of this study.

The first is built upon researches and studies that lead to a preliminary conception of an ecology of achievement: It describes a skein of achievement-centered, goal-targeted environments that do—or should—comprise the inspiring teaching and learning that can enhance the endowments of the young.

The second presents studies of unfavorable environments that block the goals of equal opportunity, optimum achievement in science, and the discovery of science proneness or talent. These unfriendly ecologies have contributed to a fall-off in the general science pool deemed necessary to maintain equitable achievement in the present postindustrial era.

The third comprises elements of formal learning in augmenting environments focusing on instruction as an event evoking early discovery through self-identification of gifted children with a particular bent (or proneness) to science.

The fourth is based in the conviction that curriculum and instruction are distinct but related fields within present models of instructed learning. It sees curriculum as serving as content within an open, facilitating structure, and instruction as a passport to activities enabling early self-identification. It provides a system for discovery and self-selection of *all* young for differentiated, sustainable futures in today's postindustrial world. Such a design would enable the young to demonstrate their powers in pursuit of their individual excellence. In short, instructional and curricular innovation combined as instructed learning constitutes a system of self-identification and discovery of early science proneness in its stage-shift to developing science talent.

The fifth exemplifies curriculum and instruction, focused in special aptitudes and abilities, relevant to science proneness as precursor to self-identification of a science talent. This goal depends on an augmenting environment, differentiated in instruction and learning, which provides open opportunity for originative inquiry resulting in a creative act. The latter criterion sample is a work, which expresses science talent. (An empirical evaluation establishes the validation of this approach as a specific criterion for self-discovery of science talent.)

The sixth concerns science talent in practice. It describes a skein of discoveries, one leading to another, and concludes with a definition of science talent.

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EXECUTIVE SUMMARY

Introduction

This study was undertaken to attempt to define some of the educational ecosystems that encourage the young to discover, first, proneness toward science and, then, if they choose, to begin actively to express that interest through science talent. It defines "education" in the manner of Bailyn (1960) and Cremin (1980, 1990) as being made much more than schooling, which is but an exceedingly important part of the ecology. The ecology of education comprises three intereffective ecosystems—that of the family-school-community, the culture, and the postsecondary systems. When these three ecosystems interact harmoniously, they form an ecology of achievement that offers all the young opportunity for their special endowments—both intellective and nonintellective—to flourish.

While the ecology of achievement is essential to all the young seeking to fulfill their individual powers, it has special implications for those students who may eventually decide on careers in science or technology. In the preindustrial agricultural world, men and women struggled primarily with nature; in industrial society, they worked with machines; in "postindustrial" (Bell's term, 1973) society, minds contend with informed minds. In this world, literate, numerate, and scientifically productive citizens are profoundly necessary. New industries, based in what Schultz (1981) calls "human-made capital," concerned with the knowledge and processes coming out of biology, chemistry, physics, space, and environmental science, call for inspiring teaching and learning in an educational ecology of achievement.

An observable model of an ecology of education—*not an organized nationwide educational system*—appears to exist in the United States. Although individuals, groups, and organizations strive to create such a skein of achievement-centered environments, a number of environments limiting achievement and unfavorable to self-discovery of science proneness hamper many of the young. It seems necessary, then, to forge programs where instructed learning becomes, first and foremost, a system of discovery of abilities through achievement, through the self-identification of capabilities by all the young in their increasing variety. Envisaged and conceivable are such programs that will validate themselves as a means of natural assessment of growth in science talent. When endowment projects itself in enriched opportunity through doing science, through performance, the young will find their own capabilities, learning how to discover for themselves and revealing portraits of intellective and nonintellective abilities. Science potential may then be discovered or confirmed not only through performance in programs in instructed learning, not only from the varieties of evidence gleaned through assessments of science proneness and talent, but also—and most importantly—through the originative work that is their criterion sample.

Limiting Environments

Before proceeding to a consideration of the qualities of environments that enable achievement in science and technology, it is necessary to look at the factors that account for the crisis that has hampered America's students' success in those fields. In 1983, the National Science Teachers Association's yearbook summarized a crisis in instructed learning in science. The syndrome of 10 it defined described a state of affairs in science education that largely continues. The yearbook's conclusion: "A wide variety of writing and reports, current projects, and research converges in a characterization of current science as plagued by 10 common recurring problems." [They follow:]

1. The textbook is the curriculum.
2. Goals are narrowly defined.
3. The lecture is the major form of instruction, with laboratories for verification.
4. Success is evaluated in traditional ways.
5. Science appears removed from the world outside the classroom.
6. A shortage of science and mathematics teachers has led to the widespread use of un- and underqualified teachers.
7. The outdated curriculum neglects the needs and interests of most students.
8. Current science instruction ignores new information about how people learn science.
9. Supplies, equipment, and other resource materials are severely limited or obsolete in most science classrooms and laboratories.
10. Science content in the elementary schools is nearly nonexistent. (National Science Teachers Association, 1983, pp. 4-11 with supporting descriptions)

In teaching and learning, what is not *open* to children early on may be *closed* to them later. And science talent is both a general category and an amalgam of personal traits and abilities focused in specific fields. While giftedness is general, talent comprises the specific aptitudes required for the subsets of a field. Individuals with various talents and exceptional competence can begin to make significant career choices even during precollege and freshman years.

Perhaps, the family-school-community, college-university, and cultural ecosystems would contribute to the brilliance of the world if, in their interconnectedness, they would lend their collaborative resources to *all* young who aspire and are capable of achieving. Then, students who acquire the trained intelligence—in whatever capacity—desiring to enter the sciences prized in the United States would fulfill their powers in the pursuit of excellence. And, as they shaped their own opportunities, they would begin to define their self-concepts as well. They would know, from the beginning, that the massive achievements characterizing scientific research generally result from the works of scientists in all categories: From artisan to novice to eminent scientist.

The mutualism of the three human ecosystems acting intereffectively within an ecology of education, is, however, not a matter of course. Because they exist within a total framework, their interaction is generally not mandated but lies within the sphere of choice, except when a specific function is dictated by law. No matter; their acts in support or neglect affect the totality of American education within an ecology of achievement.

Nothing in this study calls for a curricular and instructional experience composed of a stable set of experiences to fit all abilities and predispositions, thus attempting to ensure a steady progression through the grades. Quite the opposite, this study presses the invention of programs that encourage *differences* in expression and performance, and the inclination to seek special excellences and worthwhileness through a family-school-community program. In this sense, the limiting ecologies discussed here can stand in the path of the expression or attainment of desired abilities.

When barriers, such as limitations in instruction as summarized in the syndrome of 10, inadequately prepared teachers, and inadequate funding, combine with other factors to prevent the creation of an ecology of achievement, the results can be serious. Their consequences in the wide educational environment—especially the socioeconomic conditions affecting home, family, school, and community—can contribute to a reduced supply, first of young with interest in science and then of scientists and artisans.

Women and minorities, though making some headway currently, are particularly affected. The fall-off continues through misuse of what the Government-University-Industry Research Roundtable called the "weed and seed" approach in many of the nation's college-university ecosystems (1987). The National Science Foundation, along with other institutions concerned with the fullest representation of contributors in science, finds the origin of the present underrepresentation in early schooling, particularly in inadequate preparation in science and mathematics.

Granting that some young take the challenge of limitation and overcome it, research emphasizes that supporting environments, particularly those from early childhood through the grade school years, are generally necessary to prepare the young for the course they take in securing competence and performance.

This study aims to define an environment in schooling and education designed to encourage self-identification and self-selection of science prone and science talented young. This ideal was and is a necessary intervention (or invention), since the ecologies of both school and culture intereffect the development of abilities and predispositions, thus attempting to ensure a steady progression through the grades.

An ecology of achievement allows the intermeshing relationship of heredity and environment to encourage the full, direct expression of talent, whether in science or in another area of value in human and humane prospect. First, however, these data give rise to certain important assumptions. They follow:

1. Almost all American and foreign immigrant young who will become scientists in the 21st century are presently in our schools.
2. It is apparent for the present and possibly for the near future that a sufficient number of American young are unavailable to fill the need for the scientists of the future. Foreign scientists are now being trained here, but there is no guarantee that they will not return to their countries of origin.
3. The frequent premise that the thrust of practice in curriculum and instruction for the science talented should aim at the apex—the research scientist—requires reexamination. A visit to almost any research laboratory dispels the notion. All competent laboratories prize the contribution of skilled artisans and/or technicians. Practices in guidance and during early schooling, as well as programs, should be developed for those whose inclination is to artisanship. At present, the well-formed American system of community colleges makes available opportunities for credentials in a variety of skills.
4. Stressing achievement and self-concept at the beginning of a career in science is as necessary as stressing the history of achievement of the eminent. The latter holds up a vision of greatness as stimulus, the former, the high probability of a worthwhile lifework (however hidden from public view) and a significant contribution.

5. This construct's emphasis on limiting factors brings to mind only half the case, only part of a human ecology: The environments that make up this ecology are not severable; seeming opposites interpenetrate and, eventually, a natural ecology heals itself. In the communicable human ecology, the significant factors of materials, energy, and information engage purpose and action to introduce enabling environments to offset and replace limitations on a productive ecology.

Enabling, favored environments in intervention and invention may be able to neutralize, offset, and replace the limiting environments characteristic of flawed educational ecologies.

Enabling Achievement: An Instructional Approach for Self-Identification of Science Proneness

Here are presented some models of teaching and learning enabling expression of leaning toward science in the primary school years: First, through examination of theoretical constructs, from which are drawn clues to instructional practices that help to identify and define early science proneness; and, second, through study of practices of science instruction that encourage children to identify themselves as science prone and demonstrate their awareness prior to high school. The clear purpose: To ameliorate, if not to annul, the syndrome of 10.

By casting a wide net for excellence and equity, the family-school-community ecosystem can enable the search for and by the young for competence in general or specific performance in science. A significant improvement in science teaching may empower a larger pool of talent than selection based on IQ alone.

A model of instruction in science is offered through which children may identify themselves as science prone before the talent pool develops. Certain science lessons both demonstrate characteristic behaviors of elementary school young in various contexts and lead to self-identification of potential. This approach concurs with Havighurst's (1972) aim to design programs to meld with the potential of children early and so to increase the numbers of them who develop it.

A curricular-instructional base promoting reciprocal interaction of child and environment is essential. (It is, however, important to remember that *curriculum* is a plan for teaching in classroom and laboratory; *instruction* is what happens in these environments, the field, or in independent study [at home or library] that stimulates learning through interaction between teacher and student.)

These objectives call for "instructed learning" (Bruner's phrase, 1966). If differentiated programs are developed during the course of schooling, gifted young should have the opportunity to identify themselves early as science prone. Their path should be through personal activity in instructed learning and independent study available in a gifted environment, planned in curriculum and instruction that nurture science proneness.

At this point, formal testing is unnecessary for either self-identification by the young or as a means to prejudge their capacity. A number of field observations of the young in instructive learning situations in interdependent-independent environments are presented.

The hypothesis is that evocative instruction, consistently stimulating idea-enactive, inquiry-oriented behavior in the classroom, laboratory, or in individual work, may be used as a mode for the young early to identify in themselves a tendency to science proneness. The aim to have the young, if they so choose, do science is and was the essence of the idea-enactive, inquiry-oriented approach. And this self-definition may be followed by self-selection for further participation in differentiated curricular practice in science and in its supportive verbal and mathematical knowledge and skills. Because evidence of self-identification and self-selection of science proneness takes careful observation, the teacher becomes also a researcher and an interpreter.

A science curriculum built around conceptual schemes is flexible and responsible to children's needs and interests. Such a program, far from being rigid, permits a consistent organizing principle, one that encourages incidental learning from the media or in special environments. Such a curriculum reflects both the ways of scientists and those of growing children as they progress into and retreat from the vastness of their universe. It permits the teacher to interpret the child's questions in a manner relevant to the kind of inquiry that results in individual activity.

Equal opportunity opened up through instructed learning may result in a seeming paradox: Namely, equality of opportunity may lead to situations where differences in expression of abilities appear. Such differentiated self-expressions through early study and work may become the first instruments through which peers, teachers, parents, or others contemplate differences among students in scope and in interests. These observations may lead to a common consent that a certain child may or may not be science prone.

If idea-enactive, inquiry-oriented teaching as a strategy of instructive learning becomes general practice, *then,* in the revolving-door instructional model (Renzulli, Reis, & Smith, 1981), it may become a mode of early self-identification of the young. Their individual responses to multiple stimuli may advance a program of self-identification and self-selection through performance for the beginnings of a science talent pool. Later, early instruction may be modified into more sophisticated experimental procedure and well-ordered empiricism in the classroom and laboratory.

Idea-enactive, inquiry-oriented instruction becomes a first procedure in observing the young in early achievement in science. The complex of such behavior plus ability and achievement testing can then become part of a cumulative record, which can be compared and contrasted with *field-specific* demonstration of ability in science and mathematics. Formal testing per se is *not* to be the gate to entry into differentiated programs in science and mathematics. *If* final judgment on selection for differentiated instruction in science and math is withheld until late middle school, *after* the young have had the chance to identify themselves for it, *and* their choice is followed by consistent science-specific *works*, then we have a better picture of in-context potential signaled through performance.

National, federal, state, and local, nonprofit and proprietary, industrial and postsecondary groups are joining America's schools to advance the skills of teachers and the quality of instruction for K-12 science and mathematics. The pool of well-schooled and educated young may then increase and so too the science prone.

Enabling Achievement—A Curricular Approach for Self-Identification in Conjunction With Instruction

Siegler and Kotovsky (1986) posit that "the fit between the individual and the field is important for both intellectual and motivational reasons. A superior fit allows the individual to learn quickly and deeply the material in the fields" (p. 419). An essential element in this "fit," which in turn is necessary to the creation of a significant science talent pool, is the function of curriculum and its congruent instructed learning as valid identifiers of science talent. This study concludes that the science talent pool is incomplete until those at promise are assessed through several exemplars. The science prone give evidence of two qualities: They early show exceeding competence in acquiring knowledge in a specific field, and they early perform excellently demonstrating their powers of originative inquiry in a work. Because gifted young can begin to demonstrate heightened capacities in earliest schooling, they should be given opportunity to fulfill them in pursuit of excellence. In the particular terms of this study, they need a chance to demonstrate their science proneness.

At present, however, high school is mainly where further expression of science proneness and/or talent is empowered. Three major exemplars in the design of augmenting high school environments designed for those with promise in science are identifiable: a pervasive exemplar, another fast-paced in content, a third based in originative inquiry and enriched in acquisition of knowledge. In spite of the efforts of current reformers, most high school science programs still follow the traditional, pervasive mode in curriculum and approaches to instruction not only in the United States but also in most of the Western world. Practiced in different intensities in various high schools, this pervasive mode is based in a lecture/prepared laboratory mode with foretold conclusions generally accompanied by limited discussion. The lecture-textbook mode remains basic to instruction.

This exemplar held, in most of the observations I made in 600 schools from the 1930s to the 1980s. It is still the road to the credential to enter college and university as well as to graduation from the university. In turn, this credential opens doors to further participation of the novice scientist in the originative inquiry that adds to science and technology. As the United States tries to make its students "first in the world in mathematics and science" (original education goal 4; current goal 5, United States Department of Education, 1991), a number of curricular constructs have emerged and are emerging. What is new now, however, is instruction not curriculum. *If,* however, changes in design are introduced for the succeeding years of study—in the complexities of mathematical treatment, in computer-related inquiry, or by the science prone's compacting of subconcepts or using college textbooks in rigorous high school programs—*then,* the curriculum would *actually* be augmented in content.

In a modified philosophical approach (and, therefore, possibly a changed epistemic or axiological emphasis) in curriculum and instruction, these *stable conceptual schemes* (Kuhn's "paradigms," 1970) remain in context within a newer view predicated by the culture. The emphasis on science, technology, and society would offer a different face to the curriculum, however. In an overall updated approach to science, the nuances of a changed philosophy and, thus, a new view of the function of science in culture and society, would call for an innovative instructional stance.

Besides the science, technology, and society curriculums, the American Association for the Advancement of Science (1994) is at work on *Science for All Americans,* revising approaches to science K-12. The National Science Teachers Association *Scope, Sequence, and Coordination* (1992) offers a complementary approach for the middle school-high school years. Both these curriculums are influenced by the National Council of Teachers of Mathematics' (1991) groundbreaking *Standards*. And the National Research Council is currently writing standards for precollege science. A number of federal initiatives are also underway.

All these approaches to reform furnish at least three clear positions to those who frame explicit curricular and instructional designs.

- First, curriculum and instruction should advance the scientific literacy of the young. The imperatives of this issue are stated in clear, unmistakable aims and ends.
- Second, teachers and learners should be involved in activities that join science and technology to relevant social issues. In this, the newer technologies of science education—calculators, computers, interactive videodisks are vital.
- Third, the needs of various populations of students—namely females and underrepresented minorities—often lacking scientific literacy are brought into focus.

All the frameworks stress the idea-enactive, inquiry-oriented mode of teaching and learning—postulated here as central to instruction for *all* young—that enables the science prone to identify themselves for advanced study. Particular refinements of course content and approaches for the science prone fit readily in fast-paced and originative augmenting frameworks. Fast-paced subject matter in elementary school can lead to originative inquiry in the high school years.

My research has shown that precollege science instructional materials, whether formed in textbooks, computer programs, or initial inquiry procedures, have been cloned in conceptual structure from the curriculum structures (made into textbooks) created by the various committees at work during the curriculum reform period (1958-1962). Approaches created by scientists and teachers of the Sputnik era still appear in the textbooks of present publishers. The additions concern new discoveries and cycles of crises; the rigorous treatment has diminished, however.

This pattern holds K-12, except where videodisk technology and, at times, computers and hand-held calculators have been introduced. Future changes in design for the science prone may occur in great part by augmentation through the new possibilities of integrated mathematics and science made possible through computer-assisted instruction and inquiry. Such enrichment could also take place through the compacting of subconcepts or through college textbooks used by the science prone in rigorous high school programs.

In sum: Differentiated programs are necessary for evaluation and identification of science prone and science talented young because special curricular and instructional devices are favorable to cultivating and evoking desired abilities. Whatever the mode of selection of qualified students, their *performance* in an enabling environment differentiated to fit various abilities and skills is the most valuable identifier of future ability in science, whether expressed by the scientist or the artisan to be.

In the case of the science talented, the teacher and students reinvent the curriculum as they proceed. The dyad of curriculum and instruction as enabling environments for talented young then needs to be as innovative as are the young who will benefit from it. For they may change its future form and function. An environment in which the young discover for themselves, whether through the guided discovery of teachers or the initiative of science prone learners, is part of idea-enactive, inquiry-oriented teaching and learning, an approach that counteracts the syndrome of 10 inhibiting enabling curricular and instructional practices. Further, the idea-enactive, inquiry-oriented teaching model engenders activities that can and do serve as identifiers of science proneness in the young.

Three inferences follow:

- First, the structure of curriculum and the mode of instruction in classroom and laboratory serve to identify science proneness, an understanding that suggests a significant way to increase the science talent pool.
- Second, the widest net ought to be flung to open opportunity for all young in an idea-enactive, inquiry-oriented learning curriculum and instruction. This generous cast offers access to equal opportunity for self-identification, along with but not exclusively through ability and achievement testing, as composite factors for entry into the science talent pool.
- Third, Exemplars distinguishing three schools of thought indicate science proneness and/or science talent: a) fast-paced instruction (earlier than usual exposure to courses) with abilities measured in achievement testing; b) originative inquiry as an in-context measure resulting in a work considered to be a criterion sample of prospective science talent; c) the pervasive exemplar of curriculum and instruction in U.S. high schools, with augmenting modes in acceleration and enrichment, scholarships, and rewards.

This last (college-preparatory) model now furnishes most of the cohort composing the science talent pool and remains the matrix for present innovations in schooling. The fall-off of young with interest in science before graduation from high school and after the freshman year of college, however, is a definite cause for concern.

A newer model suggests itself. It modifies the pervasive exemplar, making provision for a differentiated curriculum and mode of instruction suited to the needs of the science prone and leading to the expression of science talent. Select science schools are increasing in number as are select programs for the science prone in heterogeneous schools.

New frameworks in curriculum, as well as new technologies, are available, but all will require modification and augmentation to fit the abilities of the science prone on their way to demonstrating talents. New technologies in science education promise certain advances in independent study and inquiry-oriented teaching and learning.

The preparation of present programs, defined by the National Education Goals (*Building a Nation of Learners,* 1991, 1992, 1993, and *The National Education Goals Report,* 1994) and designed to augment abilities in science and mathematics as well as to secure an increase in the science talent pool by the turn of the century, is only beginning. Noted throughout this study are national and local initiatives calling for an increase in resources to support the capital expenditures needed for the teaching of science—as well as the need for a full complement of teachers skilled in science and mathematics.

Enabling Early Self-Identification of Science Talent

The penultimate section of this study proposes:

- to suggest a mode by which students identify and select *themselves* to participate in differentiated programs of demanding study culminating in long-term originative inquiry
- to report observations of the young in the activities of inquiry to identify certain correlative behaviors
- to argue that, by submitting their work to examination and external evaluation by qualified scientists, students experience the peer review and tests of validity to which works in science are traditionally subjected

This section will also define a working exemplar encompassing these purposes. Originating in the late 1930s, this exemplar has gained support through usage and has accumulated a weight of evidence through constant evaluation. Study of this exemplar's analysis, synthesis, observations, and findings supports recent theories and findings.

When the young enter into the climate of science, they should benefit from at least two resources as gifts of schooling: First, they deserve access to the *substance* of science, a rich, even massive, conceptual structure of cumulative knowledge. Second, they deserve opportunities to participate in problem finding and concept seeking and forming—that is, to experience the *style* of science—its particular modes of inquiry and explanation. With these twin thrusts in mind, in the 1930s, 1940s, and 1950s, I organized curriculum and instruction encouraging the acquisition of advanced, rigorous, structurally organized knowledge, along with its companion, originative inquiry. Students solved unknowns through commitment to long-term individual probes.

My convictions about the essential value of originative inquiry programs to high school instruction in science grew from my own early experience in scientific research. The disparity between school science education and the working world of the scientists who taught me when I was young and brought me to the adventure of inquiry was apparent. I tried to set up a secondary science program close to the reality of working scientists and found that certain young—not all—were eager to give it a try.

At George Washington High School in upper Manhattan and at Forest Hills in Queens (both heterogeneous New York public high schools accommodating all students in their residential area), I made trial-and-error attempts to develop a differentiated curriculum and mode of instruction to give full opportunity to the capacities of a variety of students attending a general high school. We outlined the program at George Washington (1937-1940), later took it on a dry run there (1942-1944), and then used it experimentally at Forest Hills (1944-1954). Our program saw its fullest development at Forest Hills, and I was able to offer a first hypothesis (1947), a theory I developed more fully in the ensuing years as a result of continuing study (1951, 1955/1981, and 1988).

In such programs as that conceived at George Washington High and maturing at Forest Hills High, the young undertook research-productive, originative inquiry resulting in new knowledge, testable and falsifiable by the template of processes and procedures of mature scientists. Their achievements, written with the signature of the scientist-to-be, reflect the philosophy, the observable behavior, and the methodology of science.

In a paradigm evoking science talent, the three intereffective elements—students, teachers, and the other individuals and entities making up ecologies of achievement—support curricular and instructional methodologies that allow self-selection and identification through the methods of originative inquiry. These elements cannot be considered apart: They are an inseparable, entwined, connected, and intereffective whole. The paradigm then describes the "methods of intelligence" (Bridgman's phrase, 1945) within the "human ecological structure" (Tannenbaum's phrase, 1983). The behaviors of the scientist-to-be emerge in certain processes and procedures demanded by the constructivist experimental mode of originative inquiry and suffused by the processes of critical thinking.

Almost *never*, in my personal work with some 26 scientists prior to teaching, with 14 more during the Sputnik crisis, and with the 354 young doing originative exploration between 1944 and 1954, did I note their paths following the procession of steps of the so-called "scientific method." On the other hand, often with Bruner's "effective surprise (1966)," I saw brilliant mental breakthroughs—evidence of methods of intelligence beyond the capacity of published tests of creativity. Bridgman made this point decades ago when he wrote that the scientist, in attacking a specific problem, suffers no inhibitions or precedent on authority but "is free to adopt any course that his ingenuity is capable of suggesting to him . . . In short, science is what scientists do, and there are as many scientific methods, as there are individual scientists" (1949, p. 12). In teaching and learning, students may see the limitations of the "empirical approach" (Conant, 1952).

But scientists seem to value knowing what's wrong as much as what's right: both spur them on.

The young at Forest Hills who presented their experiments in scheduled seminars faced penetrating questions not only from the apprentice scientists and their teacher-mentors but also at times from visitors from nearby colleges and universities. These seminars evoked critical examination of problems, hypotheses, processes, and led to next steps. And finally, if the young experimenters wished to present their papers to the Westinghouse Science Talent Search, panels of practicing scientists probed their defenses of processes, of explanations, of—in fact—the caliber of their thinking. Their papers were at times published by the Talent Search, which often followed-up with reports on the careers the students eventually chose after winning the competition.

VanTassel-Baska (1984) pointed out that "the Talent Search focuses much more sharply than most identification protocols on self-selection or the volunteerism principle. The commitment to the Talent Search and to follow-up procedures must be made by students and parents in order for the identification to occur" (p. 175). Former Principal of Bronx Science, Kopelman, explaining why—of all the awards his students won—he announced only the Westinghouse, said, "A young person has to involve himself for a prolonged period in a piece of work and then do a *research paper* on it. Then the work is judged by *research people*. That's very special" (Phares, 1990, p. 53).

The special science schools, with their students selected for entry by examination, and heterogeneous schools, with differentiated programs within a curriculum open to their residential populations, did about equally well until the late 1980s in producing Search winners and runners up. And, as Search Records amply show, many finalists went on to significant careers in science, mathematics, and technology. Their awards include, for example, five Nobels, two Fields Medals, and nine MacArthur awards. Seventy percent of the winners earned a Ph.D. or M.D.

In short, select science schools and heterogeneous schools constitute different ecologies of achievement, both capable of encouraging significant originative work in science. The paradigm of originative inquiry is a way of identifying promise in students who might tend in the future to choose a career in science. As such, it deserves a firm place in differentiated curriculums in science.

My direct observation of the behaviors of the young undertaking originative inquiry in the environments of teaching and learning led me to discard the Cartesian concept of one-to-one correspondence of cause and effect and to develop a triad as a working hypothesis:

> *High-level ability in science is based on the interaction of several factors—genetic, predisposing, and activating. All factors are generally necessary to the development of high-level ability in science; no one of the factors is sufficient in itself. (1955/1981, p. 12)*

Originative inquiry calls on *general* and *special* abilities. One of the nonintellective factors is persistence, which Roe (1953) noted in selected working scientists and I (1955/1981), in the young. Tannenbaum (1983) pointed particularly to dedication and will. Environmental factors are also important, including, of course, the chance to attend a school whose opportunities included originative inquiry.

If the evidence here supports the studies of Renzulli (1978) and Sternberg (1985), both asking for reality-based intelligence tests, as well as Tannenbaum's (1983) psychosocial theory, then producing a work through originative inquiry may well measure science talent. Perhaps this finding has broader applications. Perhaps the procedures of originative research by adolescents could also indicate talent in other domain-specific fields open to originative inquiry.

Within an Ecology of Achievement—A Conception of Science Talent

Scientific judgments, concepts, and findings of fact must be testable, and thereby verified, falsified, or amended through commonly accepted processes within a community's structure. Thus, scientists and scholars seek to transmit, correct, conserve, and expand the substance of a field to achieve a continuity of cumulative knowledge. The community is usually tightly knit, given over to a particular subset of a domain (say, astronomy, biophysics, zoology, ecology, organic chemistry, ophthalmology, computer science, psychology, genetics, and the like).

Talent in science is not general. Even in the young, it may be centered in biology, physics, or chemistry, and later it is almost always shown in works undertaken within matrices—often extremely specialized ones—in given fields. Then, as required, the findings are communicated to a body of scientists through specific modes: journals, associations, and meetings. These procedures are self-energizing: The substance in all scientific works coming out of originative inquiry is subject to a well-understood style.

One of the most striking features of science talent identified in the acts of discovery is the scientist's unrelenting persistence over time. Succeeding generations create their works in part through building on prior findings. Scientists stand *on* the shoulders of others even as they stand shoulder *to* shoulder within the life-sample of a generation of discovery.

In the spirit of Bridgman's "methods of intelligence" (1949), then, this operational definition follows: Science talent in high school students is demonstrated in originative works rooted in the self-testing and self-correcting code of scientific inquiry.

The definition stems from the essential methodology of the scientist: Originative inquiry leads in its successful end state to a work that encompasses the methodologies that inspirit it—and quarrels with none. This is the premise that has affected practices within 48 states and a large body of teachers and their colleague-scientists and 50-odd years of judging by the many panels of scientists who have evaluated submissions to the Westinghouse Science Talent Search.

Talent in science is unlike that in music, art, or mathematics—where specialized aptitudes can be readily recognized in the young (Csikszentmihalyi & Robinson, 1986). Science proneness begins, I believe, in the base of a general giftedness and develops its component skills in verbal, mathematical, and, in time, the nonentrenched tasks of problem seeking, finding, and solving in specialized science fields. Eventually, given favorable ecologies, science proneness can shift to an expression in a work showing science talent.

This definition of talent in science calls for identification through in-context evaluation in long-term inquiry without reference to IQ or standardized tests of achievement. It provides for testing of science talent through a criterion sample of work of the young as predictive of their future accomplishments (Feldman, 1974, 1986; McClelland, 1973; Renzulli, 1977; Tannenbaum, 1983; Wallach, 1976).

The following sequence shows a portent of science talent in young demonstrating focused high-level ability in both acquisition of knowledge and a capacity for inquiry:

> ***First***, during the early school years, some children exhibit raw, unfocused giftedness: Their amorphous potential seems in search of a purposive expression of talent.
> ***Second***, like others' signs of a preference for music or art, some students exhibit a definitive focus towards science. Thus the science prone may shift from showing raw ability to demonstrating domain-specific interests, not necessarily excluding their attraction to other fields.
> ***Third***, given a choice later in high school (without pretest), such young may select themselves for participation in a course of study that calls for rigorous acquisition of knowledge and offers opportunity for research-productive originative inquiry.
> ***Fourth***, such young may complete an originative work and submit it to a definitive test: The scrutiny of a panel of scientists.

Such students have a solid conception of *themselves,* are secure in their *self constructs,* and employ *transformative power* (Gruber's terms, 1986). They make a choice among the potentialities claiming their recognition within self. Further experience may highlight other choices—for there are talents still to be discovered in individuals seeking excellences as yet unknown or untested. This conception embodies giftedness not as a free-floating, generality-seeking definition but as an end state in a domain-specific talent. *It is easier to measure talent expressed in a work, talent that presupposes a certain giftedness, than to try to infer from general giftedness raw traits that will project a specific talent.*

A powerful program of teaching and learning can be—or should be—a transforming experience and engage as catalyst the young in the shifting from gifts into talent. This conception lies within the postulates of Feldman's stage-shifts in the development of talent (1982), Gruber's formulation of "transformative power" (1986) as comprising giftedness into creativity, Renzulli's enrichment model (1977), and Borland's (1989) and Tannenbaum's (1989) conception of curriculum as identifier of talent.

We are not limited by inherited behaviors. Learned behaviors can engender connection and interpenetration of seeming opposites; the brain can hold alternatives (Bateson, 1979; Toulmin, 1977). Human behavior cannot be posited either as pure hereditarianism or as pure environmentalism; the two mingle inextricably (Gould, 1981, among many others).

In sum: A triad of inseparable factors can result in the expression of science talent:

1. students with promising intellective and nonintellective factors (MacKinnon, 1962; Tannenbaum, 1983)
2. teacher/mentors with the high-level abilities and personalities necessary to develop the optimum instructional and curricular environment
3. the three ecosystems that support necessary curriculum, instruction, and physical facilities

Human talent leaps out of its definition and redefines itself in more formidable expression. In time, the community of scholars engaged in research will probably decipher the human genome, particularly in its specificity in identifying the DNA components of intelligence. In time, the newer insights of the neurosciences will uncover how the meshing of physical, chemical, and physiological functions of neurons, synapses, and neurohumors function in intellection and how they create a thought, an idea, a letter, a musical notation, or a concept. In time, scientists will unearth how the three-pound brain with its 10^{12} or 10^{14} neurons and, possibly, 10^{24} synapses creates the encompassing mind. In time, researchers will develop a social invention that assures equitable access to fulfillment of human worthwhileness to unimpeded limits in pursuit of individual powers of excellence.

In time, then, we will see that what seems to remain true longest in the human scheme is that the young keep coming. And, in time, one or more of the young—always together with one or more of the old—will discover how to do what seems to escape us only to the time of its discovery. As long as the young keep coming, a surer conception of talent is foretold. As long as the young keep coming, so does the permanent agenda to search for superordinate ecologies of achievement.

My Path to This Study

Half a century of observation and study of school-communities have led toward the conclusions offered here about certain ways of stimulating students prone to science to expressing talent in its wide-ranging fields. During those years, I was fortunate in opportunities to study both scientists at work and scientists in the making. Generous latitude in time and resources for studies of methodologies in scientific research and for pertinent observation and testing of curriculum and instruction in schools, colleges, and universities allowed me to study in-depth programs and practices for the science prone and science talented.

Over a third of a century, making an average of 36 school visits per year of observation and investigation to about 1,000 schools, I clarified the conception that underlies this study of the *ecology of achievement* that is the result of the family-school-community ecosystem acting in mutualism with the cultural and university ecosystems. Further, through my study of 600 institutions representative of the broad spectrum of American schooling, I saw directly the disparities in resources and factors that affected curriculum and instruction, teaching and learning, within limiting and enabling environments.

In the planning and start-up operation of some 93 programs designed to evoke science talent, I refined my understanding of the major problems and first solutions in the conduct of family-school-community programs for the talented in the sciences and humanities in the United States and overseas.

A distillation of my studies and observations over 50 years comes together on these pages. Here are offered certain of the tested, revised curricular and instructional policies and practices useful in planning programs for developmental stage-shifts from general giftedness ——> science proneness ——> an early expression of science talent in the secondary school years.

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Science Talent in the Young Expressed Within Ecologies of Achievement

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Construct I: Toward an Ecology of Achievement—An Intereffective Skein of Achievement-Centered Environment

Life changed, as we evolved from an agrarian to a postindustrial society. In the preindustrial world, men and women struggled primarily with nature; in industrial society, they worked with machines; in postindustrial society, minds contend with informed minds. Research strongly suggests that those minds will be best formed and expressed in the most favorable environments, a human ecology of education beginning in the home, family, and community, but not ending there.

There would be no need for special differentiated programs for the young, whether served or underserved, if prior environments did not intersect with subsequent personal development and achievement. Early promise recognized and fulfilled may indeed presage high orders of achievement and creativity in originative contributions.

New Directions: Antecedents to the Postindustrial Environment

Some years ago, as if in anticipation of an enveloping global crisis, Bell (1973) and Ellul (1964) offered evidence of an evolution (a revolution?) in the environment: The reigning industrial society, ramified by significant advances in science and technology, was giving way to the postindustrial era. Bell particularly noted, for example, new industries concerned with the knowledge and processes coming out of biology (in health, genetics, and agriculture), chemistry (polymers and nucleonics), physics (solid-state physics), space science (satellites and interplanetary physics), and environmental science (global warming, damage to the ozone layers, and the effects of pollution). A postindustrial human ecology was in the making.

Bell (1973) emphasized that the antecedents of the postindustrial era lie not primarily in any one industry. Rather, postmodern industries depend upon the availability and participation of literate and numerate people schooled in language and mathematics as well as the symbolic languages of physics, chemistry, geology, biology, space science, and the like. These industries follow the precedents established by laboratory-based skills, attitudes, theory, and practice. Now, prior to 2000, recognition of this fact is stimulating a changing ecology of education.

Nobelist Schultz (1981) noted the economic benefits to society of literacy, numeracy, and scientific productivity. Science, according to Schultz is a form of "human-made capital"—embodied in its substance and style, in its literature, and in its "productive developments" not only in works resulting from a multitude of researches but also rendered by certain beneficial technologies. He cited, for example, artificial intelligence, computers, additions to food stocks like hybrid corn, resources in energy like solar power, advances in communication like satellites, and in health maintenance like pharmaceutical and diagnostic machinery. Walberg (1983), in referring to human-made capital, notes:

> To broaden knowledge of it requires the investment of scarce resources—mainly the time and effort of people—to gain future returns and satisfactions. The improved literacy—scientific, technological, and other kinds—that is the result of such sacrifices has been far more important to the industrialization of the West than is generally acknowledged. And it [human-made capital] will continue to be as vital to the well-being of postindustrial or information societies as it is for low-income countries seeking to modernize. (p. 3)

Scientific and technological sources and all knowledge workers spew out new information at a virtually inconceivable rate. Scientific data are thought to double every 8 to 10 years or even faster, rather than every 15 years as was estimated a decade ago. It seems probable that, by the year 2000, 80 to 90 out of 100 workers may engage in service industries, leaving a labor force of 10-20 percent working in manufacturing and agriculture. This shift in the labor force (affecting old and young) is already apparent.

At the beginning of the century, more than 50 percent of all jobs were in agriculture. The next greatest portion of the workforce was in domestic service. By the 1950s and 1960s, about 40 percent of American workers were in blue-collar occupations. By the year 2000, however, less than 15 percent of the population is predicted to be in blue-collar jobs; under 5 percent, in agriculture; domestic service has largely vanished. It is estimated that *non*manual labor now occupies some 80 percent of the American workforce. At present, knowledge workers account for the major part of the national output. Displaced workers often find it necessary to enter training programs to learn the new skills that may equip them to work in the postindustrial era.

In short, the postindustrial revolution is already moving at a fast pace, affecting achievement in every facet of life: The schooling and education of the young should help them sustain not only burgeoning science and technology but also prepare them to learn the new skills necessary to work in the society of the 21st century. The need, then, is not only for what has been called the "basics" in schooling but also for the literacies: the early development of knowledge and skills in language, science, and mathematics essential to the postindustrial ecology.

We stand witness to three worlds at once. The TV screen brings us visions of preindustrial society, as we see men, women, even children, contend with nature in the ecology of agrarian society; we also observe industrial societies attending to machines. And then, we watch bemused as some of our young take avidly to the technologies of the postindustrial era. They engage the new machines; they attend to artificial intelligence; they interact with incredible data bases of cumulative researches and floods of information from global sciences and technologies. The postindustrial revolution embraces a new intellectual environment, one of many opportunities evolving from the infiltration of newer substance, structure, and style of teaching and learning. (See Constructs III-V.)

In offering these new opportunities, educators may seek an environment designed to evoke rigorous achievement; they will form an ecology of education evoking enlarged human-made capital.

An Educational Ecosystem Within the Human Ecology

A concept of human ecology comprising behavior, development, schooling, and education is at hand. Herriott and Hodgkins' study of the resources of schooling's environments envisioned them as part of a human ecology "characterized as a natural unit (a type of system) that exchanges materials, energy, and information with other living and nonliving units in its environment" (1973, p. 21). Hawley (1986) conceived a human ecosystem as "an arrangement of mutual dependencies in a population by which the whole operates as a unit and thereby maintains a viable environmental relationship" (p. 26).

Numerous others have discussed and extended the concept, writing of the *ecology* of mind (Bateson, 1972); of the 21st century (new) (Botkin, 1992); of education (experimental) and of human development (Bronfenbrenner, 1976, 1979); of language (Haugen, 1972); of human[s] (Ingold, 1987); of school renewal (Goodlad, Ed., 1987); of achievement (Brandwein, 1981, 1988); of the society (Bookchin, 1980); and of human development (McGurk, 1977).

Basic Factors Undergirding an Ecology of Achievement

> The developmental transformation of an organism from one stage of its life to another is a result of the unique interaction of its genes and its environment at each moment of its life history. (Suzuki, Griffiths, Miller, and Lewontin [1986], p. 5)

This widely accepted concept is well-expressed by four researchers noted for their investigation of the expression of developmental transformation of traits. In their classic study, *An Introduction to Genetic Analysis* (1986), they present a masterful analysis and model of the interaction of gene and environment. Thus, for humans: Compare, they suggest, two monozygotic (identical) twins, the product of a single fertilized egg that divided and produced two sisters with identical DNA. Say the two were born in England but separated at birth. Suppose one were raised in China by Chinese-speaking adoptive parents. The other, in Hungary. The former will speak Chinese; the latter, Hungarian. Each will behave in accordance with the customs and values of her environment. Consider: The twins began life with identical genetic properties, but, in the end, different cultural environments produce great differences not only between the sisters themselves but also between each child and her biological parents. Suzuki and his colleagues maintain that "differences in this case are due to the environment and the genetic effects are of little importance" (p. 5).

An increasing number of studies suggest that the notion that inherited traits are unchangeable or inevitable is no longer acceptable. Studies of hereditary physical impairment continue to report amelioration through environmental intervention. For example, phenylketonuria (PKU), an inherited condition resulting in mental retardation, can be arrested by removal of phenylalanine from the diet in the very young—an environmental intervention. The ingestion of lead in the environment can lead to learning difficulties. Cases of treatment of genetic impairment through gene therapy are now coming to the fore. While full knowledge of the genetic nature of human intelligence awaits further discoveries in the mapping of the human genome, it is clear that human development, particularly learning, depends upon the intereffectiveness of genetic and environmental factors. Mann, 1994, in *Science* provides a thorough overview of the relation of genes and behavior, noting that

> In spite of the remaining contentiousness in this field, there are signs of a growing consensus that heredity plays *some* role in human behavior—a consensus that

> includes, however grudgingly, those most critical of behavioral genetics. Steven Rose of Britain's Open University, co-author of the anti-eugenics polemic *Not in Our Genes,* agrees that genetic influences "exist and are real"—the problem, he says, is society's tendency to translate this likelihood into what he calls "neurogenic determinism," in which genes determine behavior rather than influencing it in concert with personality and the social environment. (p. 1686)

Mann also quotes Plomin, director of the Center for Developmental and Health Genetics at Pennsylvania State University, " 'Research into heritability is the best demonstration I know of the importance of the environment.' . . . The same data that show the effects of genes also point to the enormous influence of non-genetic factors" (p. 1687). Says Kendler, a psychiatrist at the Medical College of Virginia in Richmond, "Genes and environment loop out into each other and feed back on each other in a complex way that we have just begun to understand" (p. 1687).

Towards an Ecology of Achievement

At present, our major effort and course of action is congruent with those who seek to eliminate *limiting* environments and, at the same time, to institute *enabling* ones that press the superarching aim of educational policy: *To seek both excellence and equity in the skein of environments combining schooling and education.*

Gallagher (1984) discussed the world-wide conflict between those who would provide for excellence, for equity, or for both. The Great Britain Central Advisory Council for Education (1967) suggested an English system that parallels the American policy of aiming to create both excellence and equity within schooling. As Gallagher observed (and other researches have supported), however, in the earliest years of schooling, equity may often call for unequal treatment for children with physical disabilities and, by implication, equally so for those with gaps in learning to make the field more equal. Johnson (1962) puts it this way:

> Every child has the right to an equal opportunity for an education. This does not mean that all children will receive the same or identical educational experiences. This means that the educational experiences provided each child will be those that will promote learning for him/her in the best way and to the highest degree possible. (p. 33)

Measuring General and Specific Abilities

The U.S. Department of Education's Office of Educational Research and Improvement notes that states using IQ scores as cutoffs in identifying "gifted and talented" students "are more likely to have larger disparities among racial and ethnic groups" (1993, p. 17). Summarizing various findings, its report on *National Excellence* cites most researchers' agreement that students should not be rigidly labeled and programs should emphasize developing children's potential through appropriate experience that allows self-identification of abilities. "We can find outstanding talent by observing students at work in rich and varied educational settings" (p. 25), according to the report.

The system of *developing* children's potential becomes also one for *discovering* their promise and talent, that is, a system of discovery, especially of self-discovery through growth in powers.

Holland and Richards (1965), Richards, Holland, and Lutz (1967), and Walberg (1971) found no definitive correlation between IQ scores and achievements and accomplishments either in the sciences or elsewhere such as music, creative writing, or leadership. Parloff, Datta, Kleman, and Handlon's examination of the achievement of Westinghouse Science Talent Search winners' projects as evaluated by scientists found IQ measures unrelated to the merit of the works completed (1968). My study of students participating in the Search (1944-1954), which paired two groups of 62 students for IQ and achievement in science, mathematics, and reading as measured by standardized tests, found *persistence* to be a most important factor determining whether students completed *originative research* or not. Such work seems beyond IQ or, as Fleming and Hollinger put it, is "non-IQ derived" (1981). Barron wrote that the individual's level of interest in and commitment to the subject matter of his/her field are "almost invariable precursors of original and distinctive work" (1969, p. 3).

Renzulli (1978) posited three areas of expression of giftedness—*above-average ability, task commitment,* and *creativity.* Within his revolving door identification model, students may choose to express their abilities within three enrichment models (Renzulli, 1977; Renzulli, Reis, & Smith, 1981). The first calls for students' high-level mastery of the curriculum; the second for their use of methods, materials, and techniques to do research using sophisticated thinking skills; the third, to work in individual and small-group investigations that provide opportunity for the development of a creative product, a *work.* Thus, intellectual ability appears not only in mastery of a field of interest but also through active expression in originative work.

Siegler and Kotovsky (1986), reviewing the studies of 17 contributors to Sternberg and Davidson's *Conceptions of Giftedness* (1986) described a surprising degree of consensus:

> The definitions of giftedness advanced in this volume are remarkable both for the degree to which they disagree with this popular stereotype[1] and for the degree to which they agree with each other. Csikszentmihalyi and Robinson, Feldhusen, Feldman, Gallagher and Courtright, Haensley, Reynolds, and Nash, Renzulli, Tannenbaum, and Sternberg all define giftedness as involving multiple qualities. These qualities are not just intellectual. All of the investigators argue that giftedness involves social and motivational properties as well. All view IQ scores as inadequate measures of giftedness. Task commitment, high self-concept, and creativity are explicitly mentioned by many or all of these researchers as being among the defining qualities of giftedness. (pp. 417-418)

Interdependent and Interpenetrating Intellective and Nonintellective Factors

Tannenbaum has noted that

> Keeping in mind that developed talent exists only in adults, a proposed definition of giftedness in children is that it denotes their potential for becoming critically acclaimed performers or exemplary producers of ideas in spheres of activity that enhance the moral, physical, emotional, social, intellectual, or aesthetic life of humanity. (1983, p. 86)

[1]That is, that IQ scores reify giftedness or talent.

His definition sustains a general consensus to cast the widest net at the onset to be sure not to neglect children whose high potential may be all but hidden from view.

As will be seen, while science talent is generally accepted as existing only in adults, aspects of it may in fact be identified and encouraged in adolescents. With beneficent curriculum and instruction, in inspirited instructed learning, through the opportunities offered for individual inquiries that culminate in originative works, the talent of the young to solve unknowns can and does emerge. Thus, a child's tendency for promise in science (science proneness) can be identified early in elementary school through programs of instructed learning. Then, through the "maturing stage shifts of development" (Feldman's phrase) coming out of further opportunities in originative inquiry, high school students may produce empirical expressions of science talent (Constructs IV and V).

Facilitators of Achievement

Tannenbaum proposed five intereffecting internal and external factors facilitating the expression of giftedness and talent. These facilitators are

- *intellective,* as manifest in tested general IQ
- *general and special abilities*—the particular capacities and affinities for particular kinds of work (in respect to science, capability in both mathematics and science content)
- *nonintellective*—traits integral to the achieving personality regardless of the area in which the talent appears (they include ego strength, commitment to a chosen field, willingness to sacrifice short-term satisfactions for long-term accomplishment)
- *environmental* features of the human ecological structure (home, school, and community settings; parents who serve as role models; classroom instruction; peers' attitudes; neighborhood resources [presence or absence of museums, libraries, and the like])
- *luck* or *chance* (unpredictable events in a person's life "critical both to a realization of promise and to the demonstration of talents. . . . There are many unforeseen circumstances in the opportunity structure and in the prevalent life style that can make a big difference in the outlets for gifted performance" (1983, p. 88).

By definition, luck escapes conventional methods of measurement.

Passow had noted the impact of Tannenbaum's facilitators when they function positively in concert in individual performances (1985). On the other hand, the absence of one of those facilitators often becomes a limiting factor in teaching and learning. Twenty-some years earlier, in his study of architects, MacKinnon proposed, "Our data suggest, rather, that if a person has the minimum intelligence required for a mastering of a field of knowledge, whether he performs creatively or banally will be *crucially* determined by nonintellective factors" (1962, p. 493).

The Play of Nonintellective Forces

American educators generally predicate achievement on the presence of a reasonably average IQ (around 100). They tend to assume its importance as a factor in assessing not only general ability but also special abilities. But individuals lacking certain nonintellective factors do not express these abilities in outstanding achievements.

The National Education Goals Panel Reports (*Building a Nation of Learners,* 1991, 1992, 1993, and *The National Education Goals Report,* 1994), without so labeling the importance of nonintellective qualities, still note their effect. At various points, the reports attribute the "real" performance gap (1991, p. x) between American students and their counterparts in other industrialized nations to factors such as "a misplaced sense of self-satisfaction" (1991, p. x), "lower expectations" (1992, p. xii) on the part of parents, and the importance of "positive attitudes" (1993, p. 6). Even the addition in 1994 of two more Education Goals calling for safe, disciplined, and alcohol- and drug-free schools and for active parental participation in their children's learning shows awareness of the importance of nonintellective qualities.

Admitting the difficulty of testing unlike populations (see Rotberg, 1990), the 1992 National Goals Panel Report summarizes "Our achievement scores in mathematics, and to a lesser extent science, are below those of most other developed countries. Findings of this type have been relatively consistent for over 25 years, despite differences in the manner in which these comparative examinations have been conducted" (p. 7). The 1993 Report notes that "American 13-year-olds are more likely to do science experiments, to use computers, and to have books in their homes than their counterparts in other countries. However, American students tend to spend less time doing homework and lead the nations in the amount of TV watched" (1993, p. 108). Further, the Report continues, "In 1990 and 1992, students in higher grades were less likely to have positive attitudes toward science and mathematics than students in lower grades" (1993, p. 110).

The Office of Educational Research and Improvement's 1993 report on *National Excellence* offers other examples of important nonintellective factors. It cites a study comparing the top 1 percent of U.S. students taking Advanced Placement courses with top students in 13 other countries. According to its findings Americans were 13th out of 13 in biology; 11th out of 13 in chemistry; and 9th out of 13 in physics (p. 9). This showing stems *not from failure of our young's intellect,* according to the report:

> America's top students have the potential to achieve at the same levels as do their international counterparts, but our students are not challenged to do so. Top-performing students in the United States spend less time in school, spend less time outside school doing homework, and are not asked to work with challenging materials as often as their peers in other countries. According to several studies, more than half of our gifted students fail to achieve in school at a level commensurate with their abilities. (p. 11)

What may be at work is not the lack of intellective abilities but the intereffecting conglomerate of *non*intellective factors, such as drive, commitment, and environments that foster ego strength. With these nonintellective qualities at the baseline, the young's application to study can embrace both acquisition of knowledge and readiness to do originative inquiry. The "collective message" of Americans' poor performance on international tests (although the Report does not fail to note that tests are imperfect measures of creativity, leadership, potential, and other "important human qualities") is "disturbing: America demands less of top students than other countries do. At the same time, our need for the highest levels of skills and expertise is on the rise, many of America's most talented students are being denied a challenging education" (1993, p. 12).

In spite of often discouraging educational environments, some of those gifted students, are managing to succeed brilliantly in many fields. The stunning work of many of the students who participate in the Westinghouse Science Talent Search, for example, is the result of both their intellective and nonintellective skills. So is the achievement of the six public high school students who made up the U.S. team in the International

Mathematics Olympiad, becoming the first squad in the contest's 35-year history to make perfect scores, and thereby defeating the 68 other nations competing (Van Biema, 1994).

The 1992 National Goals Panel Report points out that "relative to population, the United States awards more undergraduate science, mathematics, and engineering degrees than France, Germany, and Italy, but 21 percent fewer than Japan" (p. 8). The implication appears that, once Americans get to the university, they *are* challenged to perform. In this light, is it necessary to conclude that the nonintellective factors that would make such achievement possible are not encouraged by our "system" of precollege schooling? Are such qualities lacking both in the students' extraschool environment of home and community and in the curriculum and instruction they face within and without classroom walls?

Put another way (as it seems often to be recently), are America's culture and its methods in quest of achievement as rigorous as those of other countries? We often compare ourselves to Japan in these respects. Too often, however, a nation's ecology of achievement is embodied in the regulatory function of a centralized government that reflects its culture. Then, the cultural ecosystem dictates the habits and functions of the family-school spheres as well as those of the college-university. Japan, for example, does not embrace the multiracial, multiethnic cultures that make up the United States. Indeed, Japan's arrow of achievement may be the result of the government's singular control of its ecology of education, one that can truly be called (in a way that ours emphatically cannot) an "educational *system*" with a singular corporate structure. Thus, Japan's family-school-community, cultural, and college-university ecosystems combine to form a rigorous, articulated ecology with a thoroughly integrated aim and methodology.

Former ambassador to Japan, Rohlen, who lived in and appreciates the nation's customs and habits, asked in the 1985/1986 *American Scholar* "Japanese Education: If They Can Do It, Should We?" His answer is negative: Rohlen believes that the Japanese pattern *is* not applicable to the United States and *could* not work in America. We are instead required to motivate the considerable reservoirs of rigor present in our ecology of achievement.

Husén (1979) questioned the comparability of international assessment as well. Essentially, he argued, tested cohorts of students in the United States are not comparable to those of Sweden and Germany because the latter countries' scholastic standards eliminate many students whom the community designates as unprepared. While American high schools graduate "more than 75 percent, those retaining and completing gymnasium (grades 11 and 12) is some 45-50 percent, and in the Oberprimaner (grade 13) in Germany, some 15 percent" (p. 97). (The 1993 Goals Panel Report notes an improving high school completion rate [87 percent for 19-20-year-olds and 88, for 23-24]; the dropout rate [for 16-24-year-olds] has also declined from 14 percent in 1975 to 11 percent in 1992 [pp. 40, 42]).

In sum, we do find gaps in achievement among the young learning in the different ecologies of achievement that reflect individual countries' cultural approaches to schooling and education. Certain American beliefs and aims, stated or unstated, differ from those of other countries. Perhaps the gaps are not so much in the young's achievement as among the ecologies that interact with their intellective and nonintellective traits. Perhaps methods of neutralizing environments that cultivate deficiency require the steadying reform of the entire intereffecting ecology of education as it reflects a national culture—and its view of its place in an era demanding the consistent contribution of human-made capital.

Towards an Ecology of Achievement: Intereffecting Endowment and Opportunity

In *Identity and the Life Cycle,* Erikson considers, among other things, the growth of youthful ego-identity accompanied by "successful alignment of the individual's *basic drives* with his *endowment* and *opportunities* (1959/1994, p. 94). Further, an "accruing ego-identity gains real strength from whole-hearted and consistent recognition of real accomplishment, that is, achievement that has meaning in the culture" (p. 95).

Several reform reports have emphasized that the school exists embedded within the community, while significantly enlarging the concept of community as it applies to schooling. The Carnegie Foundation, for example, wrote that "Whether a school succeeds or fails in its mission depends on the degree of support received from the community it serves, both locally and nationally" (1988, p. 41). That is, the success of a school's mission depends on the alignment of sufficient opportunities to enhance the endowment of all its students, not only the apparent endowment they bring upon entry but also the enhanced endowment made possible by the enriched opportunities offered by harmoniously functioning family-school-community ecosystems. (See Construct II for a discussion of the well-documented fall-off in a variety of such opportunities.)

The National Commission on Excellence in Education emphasized that the federal government has *"the primary responsibility* to identify the national interest in education" (1983, *A Nation at Risk,* p. 33). The national government, it continued, "should also help fund and support efforts to protect and promote that interest. It must provide the national leadership to ensure that the nation's public and private resources are marshalled to address the issues discussed in this report" (p. 33). These reports and others adhere to a new view of the mission of schooling: To serve the culture necessary to the postindustrial era, schools should stimulate achievement of young and old to full capacity. But the schools are no longer asked to accomplish this task alone (and they should not have been so saddled in the past). They are now seen as existing within a wide interrelationship, within an ecology of education made up of three interpenetrating ecosystems—that of the family, school, and community, that of the surrounding culture, and that of colleges and universities. When this ecology works, it becomes an ecology of achievement that aligns resources and facilitates endowment and opportunity.

Such environments in the componented ecology of achievement in teaching and learning provide the human and physical resources of information, materials, and energy necessary to attain certain essential goals (Herriott & Hodgkins, 1973, p. 1). Namely, the schools and community should attempt to fulfill the needs of the young, so they may develop their individual endowments by taking advantage of their cultural and educational endowments to fulfill their powers in environments furthering growth. *To achieve fully, to realize their gifts, children require the support of a gifted environment of resources and people.*

New Models? New Definitions?

Lazerson, McLaughlin, McPherson, and Bailey defined the "totality of American education" as one in which "the cultivation of an informed and expanded intelligence, the enhancement of creative expression and critical thinking, and the development of active and meaningful citizenship cross regional, racial, and class lines" (1985, p. xvi).

In considering the consensus and conflict apparent within the so-called American educational "system," Kaestle wrote,

> The new models will have to accommodate competing identities, intragroup as well as intergroup conflict, and a pluralism of conflicts in different dimensions of life. . . . What appears to be an American consensus on education is to some extent the result of ambivalence, muted conflict, and trade-offs. The American public school is a gigantic standardized compromise most of us have learned to live with. (1976, p. 396)

New models of education in America, however titled, however fulfilled in the ecologies of achievement they empower, will as a matter of course have to resolve such "competing identities" in synergistic activity if they are to focus on children's achievement of desired abilities. Ambivalence, muted conflict, and trade-offs may diminish, if the totality of American education aims to create an ecology of achievement worthy of the superarching future.

Components of an Ecology of Achievement as a Structure of Schooling and Education

How useful it would have been if countless well-intentioned writers had not tried to graft onto the school ecosystem the functions of enormously diverse national cultural ecosystems outside the schools but had instead followed what Bailyn (1960), Cremin (1980, 1990), de Lone (1979) and others had analyzed as a disjunction between schooling and education. Our schools have "succeeded" or "failed" when they have or have not met the objectives of the communities that support them, but the American educational system has not and could not have failed.

The American educational system does not yet exist as a national *system* of integrated functions. For example, it is quite possible to find two schools serving about the same number of students, one low and one high in assessment of similar objectives of student achievement. The difference between the two may stem in part from disproportionate funding and resources—most American schooling is financed locally, and rich communities support schools much more generously than poor ones—that lead to unequal facilities and materials. (See Construct II.) It is also the result of differing amounts of school support from the other ecosystems undergirding the educational ecology—namely those of the community and family, the culture, and the postsecondary structure.

A Synergism of Ecosystems

The geography and functions of the three ecosystems (defined below in this section) will be discussed throughout this study in terms of their instructional, curricular, and administrative functions.

Clearly, the local family-school-community (an ecosystem centered in teaching and learning) depends for funds and materials essential to certain critical administrative and curricular functions on community, state, and national policies. To thrive, children need the interaction and support of not only their family-school-community ecosystem but also their cultural and postsecondary ecosystems.

An ecosystem, of course, may be big or small. The all-embracing world ecosystem is the biosphere. Within it are large ecosystems—of desert, forest, or plain, for example—and small ones—a wood, a pond, or the artifice of an aquarium. The total so-called

American "school system" encompasses within it a huge number of local ecosystems formed by the combination of families, schools, districts, and their communities.

The family-school-community ecosystem is the first unit in the ecology of achievement that begins to give the young scope for their achievements; however, different families, schools, and communities offer different qualities of resources to their young (see VanTassel-Baska and Olszewski-Kubilius, 1989). Each family-school-community ecosystem, small as compared to that of the culture as a whole but exceedingly numerous individually,[2] exists in a kind of symbiosis, each part closely interdependent; if successful, this ecological mutualism contributes directly to the healthy development of the learners' lives.

My study of crises in schooling (1981) follows Bailyn (1960) and Cremin (1980, 1990) in distinguishing between schooling and education. As they did, I used the term "educational" ecosystem to define the whole of which schooling is but a component; Goodlad calls the similar entity a "cultural" ecosystem (1987). By whatever adjective, all these studies emphasize the same large whole of which the family-school-community is but one exceedingly important part. Bailyn's and Cremin's point that the family-school-community is not fully encompassed in the educational system is not always understood, however, even with Goals 2000 on America's horizon. One section of the educational ecosystem should not be praised or criticized without attention to the others. For the whole is larger than the sum of its parts. And the whole is centered unremittingly in achievement.

Some Early Delineation of the Sectors Within an Ecology of Achievement

The family-school-community ecosystem primarily attempts to transmit the concepts, values, and skills prized by a community enfolding a school to mutual benefit of its parts.

The postsecondary ecosystem continues the formal education begun in the family, precollege schooling, and the community. Its entrance requirements influence its instructional, curricular, and administrative practices; so does its stance as part of a public or private ecosystem.

The cultural ecosystem penetrates all educational practices that affect and effect changes in behavior relating to the achievement of stated goals. These behavioral changes, which take place in many environments, may be of habit, of character, of conduct, of self-expression, of intellect, of time, or of culture; they occur throughout life and its transitions.

Such transitions are not necessarily equated with formal rites of passage, such as graduations or exits from formal schooling and education, public or private. Thus, for example, within the cultural ecosystem, education can occur in environments outside of the schoolhouse: In those niches given over to the executive, legislative, judicial, moral decision-making functions of home, family, community, state, and nation; in churches, synagogues, temples, mosques, and the religious encounters of nonchurchgoers; alone, and with peers. Schooling and education can exist in chance or planned encounters; through direct experience or through the media (especially TV, that other motivating life); in newspapers, books, and magazines; from reaction to failure and success; on the job or at leisure; in illness or recovery; from crises generally. Deleterious education also occurs in environments that contradict the kinds of achievement praised by the culture by encouraging drug abuse and/or criminal activity, the bane of both young and adult. Such

[2]According to recent counts, the United States now comprises about 16,000 school districts.

toxic environments, while part of what Bailyn (1960), Cremin (1980, 1990), and Goodlad (1987) consider the educational or cultural ecosystem, deliver their messages through the school of "hard knocks."

As noted, the cultural ecosystem also intersects a third ecosystem that comprises all postsecondary environments—community and junior colleges, colleges and universities, and postgraduate institutions. Both these ecosystems affect the decision-making processes of the family-school-community ecosystem, which in turn interacts upon and with the other two. Whether acting separately or mutually, both the cultural and postsecondary ecosystems contribute significant operating funds for the schools as well as provide rules for their use. (Schools, which receive federal, state, and local monies, send their graduates to colleges and universities, if those students can meet particular entrance requirements. Sometimes, students are awarded scholarships.) As well, the three ecosystems provide custom and law governing the practices that determine the modes of articulation of complementary ecologies.

Recent Federal Initiatives

To achieve the Math and Science Education Goal and to fulfill the aims of the America 2000 legislation, the nation will be required to look to the health of its ecology of education. That too is the purpose of this study. The Goals 2000 legislation endorses the development of national content standards for education and assessments to measure their attainment; it also provides funding for states to reform their schools in line with these goals. While attending to the needs of all, however, as U.S. Secretary of Education Riley, points out, it is also essential to help develop individual gifts (and to provide extra support for those with disadvantages):

> More than 20 years have elapsed since the last national report on the status of educating gifted and talented students. . . . Youngsters with gifts and talents that range from mathematical to musical are still not challenged to work to their full potential. Our neglect of these students makes it impossible for Americans to compete in a global economy demanding their skills. (Office of Educational Research and Improvement, 1993, p. iii)

Secretary Riley calls attention to a failed alignment of endowment with opportunity.

The crisis in schooling and education affecting achievement of American students, particularly in the fields of science and mathematics, has not yet abated. And it is occurring in an onrushing postindustrial era that centers in the achievements of numerate and literate young, particularly those equipped in the sciences (Bell, 1973). If the opportunities in the interconnected environments of the three ecosystems favor the development of the knowledges, attitudes, and skills that fit the young for this era, more of them will probably participate in its growth. Hence, the vital need for broader opportunity for self-identification of potential and self-discovery of desired paths to fulfillment of personal endowment. This need calls for an alteration in the current ecology of education in line with the model of the ecology of achievement and other inventions in instructed learning defined in Constructs III-V.

Construct I Implications

The urgency of the postindustrial era has shaped our aims and ends for the restructuring of schooling and education. To cope in thought and action with the incredible changes that may be but preliminary, an ecology of achievement (by whatever name) furnishes a model with which to think.

Achievement as accomplishment and as one goal of life and living, however, is not a naive concept. Such an aim dictates that individual endowment aligns with opportunity for fulfillment of individual powers in the pursuit of excellence. Note, these powers are both intellective and nonintellective. *Gifted* students require an environment *gifted* in its support of *all* young; at the beginning no one can foretell what giftedness may be evoked in enabling environments that supersede early experiences flawed by interaction with inadequate ecologies (see Tannenbaum, 1983).

An observable model of an ecology of education—*not* an organized nationwide educational system—appears to exist in the United States. The structure of this ecology comprises three ecosystems through which humans and environment interact, through philosophy and practice, to initiate the young through schooling and education into the culture. If these three ecosystems (in the thousands throughout the land) of family-school-community, culture, and college-university live in mutualism, they lock in an ecology of achievement. The family-school-communities embrace *similar* niches mostly concerned with teaching and learning to catalyze the growth of the young both in their intellective and nonintellective capacities. In contrast, the larger cultural ecosystem comprises *dissimilar* niches, which also educate; these, for example, include governments, other public and private institutions and organizations, peers, TV, and other media. The third includes proprietary institutions and colleges, universities, and postgraduate schools. The latter two ecosystems form what can be a chancy ecology, where achievement depends not only upon *intellective* factors but also on *nonintellective* components such as individual initiative, persistence, environment (including level of prosperity or poverty), and luck for advancement into a career or a profession.

Both cultural and postsecondary ecosystems affect the family-school-community ecosystem and, thus, the eventual career choices of the young. One may speak of an educational system in certain countries—Japan, for example—because a general policy and practice in the schools throughout the country guide uniform aims and emanate from a central governing structure. Japan's civilization can also be seen as a cultivated cultural ecology. Similar structures guide schooling and education in many Mideastern countries, in Europe, and in South America. In the United States, in contrast, we have an *ecology of education,* which—if it works—becomes an *ecology of achievement.*

Towards a Steadfast Ecology of Achievement

Granting the assumption that some young take the challenge of limitation and overcome it, most research emphasizes that supportive environments, particularly those from childhood through schooling, are essential in preparing the young to pursue and fulfill their special competence and performance.

Thus, through the triumph of persistent, intelligent advocacy, all 50 states have formulated legislative policies that support educational programs for the gifted and talented (Passow & Rudnitski, 1993). This trend shows a welcome advance in structuring an ecology of achievement, but such programs may be insufficient to serve the events of the future. The greater victory would be for policies supporting educational programs that, from their inception are pervasive, in reaching all the young. Policies like these would aim to help all children pursue their personal excellence without prejudgment through assessment of intelligence and/or ability.

It seems necessary, then, to forge programs where instructed learning becomes, first and foremost, a system of discovery of abilities through achievement, through the self-identification of capabilities by all the young in their increasing variety. Envisaged and conceivable are such programs that will validate themselves as a means of natural assessment of growth in science talent. When endowment projects itself in enriched opportunity through doing science, through performance, the young will find their own capabilities, learning how to learn and to discover for themselves and revealing portraits of intellective and nonintellective abilities. Science potential may then be discovered or confirmed not only through performance in programs in instructed learning, not only from the varieties of evidence gleaned through assessments of science proneness and talent, but also—and most importantly—through the originative work that is their criterion sample. Constructs III-V will develop strategies and tactics for creating a program of discovery, through self-identification, of science proneness and talent through instructed learning.

First, however, it is necessary to banish the vestiges of failed ecologies of education. Construct II describes such limitations, which have hampered our capacity to furnish the opportunities necessary to build a system that encourages the discovery of science talent, one that aligns endowment with opportunity.

Construct II: Limiting Achievement—Environments Unfavorable to Self-Discovery of Science Proneness

Generally speaking, it seems reasonable to assume that the effectiveness of an ecology of *education* would—or should—be judged as to whether it were an ecology of *achievement* after the generation who learned in it has affected life and living. Instead, some try to predict the future contributions of the young during their years of instructed learning according to their performance on generally accepted measures of achievement such as standardized tests.

The Syndrome of 10: Accounting for the Crisis

In 1983, the National Science Teachers Association's Yearbook summarized a crisis in instructed learning in science. Its analysis is still cogent: Research into the 1990s shows that it described a state of affairs in science education that largely continues. The Yearbook's conclusion: "A wide variety of writing and reports, current projects, and research converges in a characterization of current science as plagued by 10 common recurring problems." [They follow:]

1. The textbook is the curriculum.
2. Goals are narrowly defined.
3. The lecture is the major form of instruction, with laboratories for verification.
4. Success is evaluated in traditional ways.
5. Science appears removed from the world outside the classroom.
6. A shortage of science and mathematics teachers has led to the widespread use of un- and underqualified teachers.
7. The outdated curriculum neglects the needs and interests of most students.
8. Current science instruction ignores new information about how people learn science.
9. Supplies, equipment, and other resource materials are severely limited or obsolete in most science classrooms and laboratories.
10. Science content in the elementary schools is nearly nonexistent. (National Science Teachers Association, 1983, pp. 4-11 with supporting descriptions)

Confirming Studies

The National Science Teachers Association's findings are substantiated by much other data, including a synthesis of four massive studies made after the first litmus tests of the early 1970s: (a) Helgeson, Blosser, and Howe (1977) summarized the status of precollege science in the years 1957-1975; (b) Weiss (1978) surveyed teachers, administrators, supervisors, curriculums, course offerings, teaching methods, support services, and demographic information in the 1977 *National Survey of Science, Mathematics, and Social Science Education*; (c) Stake and Easley (1978) reported 11 case studies of schools representing different types of communities; and (d) the *National Assessment of Educational Progress*[3] (National Center for Education Statistics, 1992)

[3]According to the National Science Board (1993), the *National Assessment of Educational Progress* has for almost 20 years been the federal government's primary indicator of student achievement. That the tests are "low stakes" has caused some observers to question whether student motivation to succeed was high (pp. 4-5). This concern further reflects awareness of the importance of *non*intellective factors in achievement.

noted that students' interests in science decreased between the third and seventh grades, and declined further between the seventh and eleventh grades.

Among the National Science Teachers Association sources was the National Science Foundation's *Project Synthesis* (1978). Its more than 2,000 pages gathered and interpreted information from three Foundation status studies and the *National Assessment of Educational Progress* reports. The general research procedure characterizing *Project Synthesis* was the discrepancy model used for qualitative research. Basic to this design is the development of ideal-state conditions, compared with description of actual states. Discrepancies are then identified, making possible recommendations for future decision making and revisions.

Other researches done in the 1980s note symptoms similar to those listed in the syndrome of 10. Studies by Yager (1980a, 1980b, 1982a, 1982b), the comprehensive Roundtable Report (1987, summarized below), and the masses of observations and data presented in the Triangle Coalition for Science and Technology Report (1988) summarized a lack of effective instruction and curriculum in science. The reports asserted that, because instructed learning is flawed, achievement is seriously below standard. That situation, according to the National Science Board's most recent *Science and Engineering Indicators* (1993), while showing some spotty changes, has largely remained the same. These findings will be reported in the next section.

In 1984, scientists, engineers, administrators, and representatives from government, universities, and industry gathered for a Government-University-Industry Research Roundtable designed to explore ways "to improve the productivity of the nation's research enterprise"—the foundation of its human-made capital. Its subsequent report, *Nurturing Science and Engineering Talent* (1987), suggested ways to stimulate actions to enhance the achievement of the young in science and mathematics and thus to increase the number electing to pursue careers in such areas. Implicitly, the Roundtable defined science talent as high-level achievement in science. *Nurturing Science and Engineering Talent* noted the six following hurdles to such progress.

1. The early years are critical: "By grade 10, four-fifths of students are already lost to the science and engineering talent pool judging by expressions of interest in mathematics, science and engineering careers" (p. 25). By grade 10, most students have taken the often required two years of science (general science and biology). After sophomore year, considerable dropouts occur: Before 1987, less than 20 percent of juniors and seniors took both chemistry and physics. In 1989, however, 45 percent were taking chemistry and 20 percent, physics.
2. "By the 10th grade, boys are three times more likely than girls to express interest in mathematics, scientific, and engineering careers" (p. 26).
3. "Low socioeconomic status plays a major role in the underrepresentation of minorities." Parental educational attainment, occupation, and income is a strong influence at this stage, affecting values and formal and informal educational activities that have a major impact on the development of children's interests and abilities (p. v).
4. "The central aptitude that tends to separate the scientists from nonscientists is mathematics knowledge" (pp. 130-131, Rever, 1973). Sells (1978), reporting on mathematics preparation as a "critical filter" to science careers for minorities and women, noted lower levels of participation in higher level nonrequired mathematics courses by White females and all Black teenagers among samples of high school students in California and Maryland. The consequences of choices and/or opportunities that result from high school

course-taking behavior can effectively limit career choices in college. Tobias described a similar flight from mathematics among many able college women (1994), although she found that undergraduate women already committed to science and engineering fields tend to be, unlike their sisters in the humanities, unafraid of math.

5. "Major losses to the science and engineering talent pool occur during the college years" (p. 29). The Report estimates that, by college graduation, only 35 percent of the seniors who planned on science, engineering, and mathematics careers have stayed with their plans. The Roundtable notes that this dropout rate needs increased attention: Both university curriculums designed to weed out and to nurture students need examination, as well as the extent of interaction between students and senior faculty.
6. "The long- and short-term earning prospects of different occupations do influence what majors students choose" (p. 29).

Consistent Patterns

A curious relationship between the reforms of 1952-1962, which peaked when Sputnik appeared in orbit around the planet in 1957, and those of the present is that both movements defined the problem in terms close to those summarized in the syndrome of 10. Today's discussions try to solve the same kind of problems with which the Physical Science Study Committee (PSSC), the Biological Sciences Curriculum Study (BSCS), and Chemical Education Materials Study (CHEMS) wrestled 30-40 years ago.

It is instructive that all these groups of science education reformers—in the 1950s, 1960s, 1970s, 1980s, and, now, the 1990s[4]—were and are primarily concerned with parallel goals. To neutralize the syndrome of 10, they all sought to

- build an environment based in inquiry teaching in all the sciences throughout the school program and to create the foundation essential to a conceptual approach
- meld the kind of inquiry-based teaching and learning that would help the young establish the ladder of concepts necessary to foresight and understanding of modern science
- update science knowledge and obtain the resources necessary to maintain inquiry teaching characteristic of science particularly through uses of laboratory and field study
- provide curriculum and instruction for *all* young in science, including different options for the science prone and the science talented.

The syndrome of 10 applies not only to crises in science education but also to flawed recurrent practices in instructed learning in other areas of schooling. This hypothesis seems worth research: A drift of schooling and education into a similar

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[4]To mention just a few federal initiatives: The Department of Education's Office of Educational Research and Programs for Elementary and Secondary Education (particularly, in recent years) through the Eisenhower Program for Mathematics and Science Education, the National Science Foundation's Statewide Systemic, Urban, and Rural Initiatives, the National Academy of Sciences/Smithsonian's National Science Resources Center, and the National Research Council's work on developing standards for science in the same vein as the National Council of Teachers of Mathematics's ground-breaking work in math. In addition, the National Science Teachers Association and the American Association for the Advancement of Science are both at work on new precollege science curriculums.

syndrome could serve as an early warning system of a failing environment in instructed learning.

The Syndrome's Ramifications in Instructed Learning

The limiting environments described in the syndrome were and still are pervasive. Goodlad's *A Place Called School* (1984) called attention to the decline in facilitating environments in schooling. So did Sirotnik's (1983) study, based on data gathered from many classrooms in 13 elementary schools, which also were part of Goodlad, Sirotnik, and Overman's "Overview of a Study of Schooling" (1979). Sirotnik found that "there is little variety in teaching practice across the country . . . the majority of class time is spent in teachers lecturing to the class or students working on written assignments." He reported that teachers out-talked students by a ratio of nearly three to one (p. 20). Sirotnik estimated that on average "just under 3 percent of the instructional time that the teacher spent with students involved corrective feedback (with or without guidance). At the secondary level, this estimate is less than 2 percent" (p. 19).

The situation is not new, and it has not everywhere changed. Stevens' turn-of-the-century four-year study of secondary school teaching revealed that science and mathematics teachers generally followed the processes of teacher talk and reading the textbook (1912). Hoetker and Ahlbrand (1969) and Peterson and Walberg (1979) also emphasize the dominance of lecture.

During my three decades of observations of science programs within the curriculums of a sample of 600 schools, I found 122 classes in high school physics and chemistry where teachers generally out-talked or over-directed students by a ratio of over four to one (three to one in both biology and general science). In physics and chemistry, a teacher often demonstrated an "experiment" by setting up equipment as students attended both to empirical method and result; questions by the teacher, at times by students, sometimes accompanied the lecture. Other times, s/he illustrated a problem's solution, made several assignments for the students to do in seatwork, and then directed students to demonstrate their findings and explain their work at the chalkboard. One laboratory period per week, its conclusion foretold in manuals, was general in about 60 percent of the classes I observed; one every two or three weeks in the rest. In any event, the lecture-textbook, laid-out laboratory approach was followed in most courses, particularly those in college preparatory programs. There, the lecture mode was deemed useful partially because it is modeled after methods often used in college and university ecosystems.

The responses of many of the reformers of the 1990s suggest that not much has changed in the past decade. But there *were* exceptions then, and there *are* now. In 130 of the 600 schools I observed between 1951 and 1981, I found teachers avoiding straight lecture in biology and chemistry classes. Such teachers engaged in laboratory study, demonstration, discussion, and interaction in inquiry-centered instruction in well-devised facilities. Their schools were ecological oases of achievement that enabled the expression of science proneness. Sirotnik also emphasizes the exceptions to an often lackluster landscape, stating that "It would be a grave mistake to interpret what I have reported and commented upon as an indictment of teachers and schools. There are exceptional schools and teachers quite atypical of the aggregated profiles presented here" (p. 29). He stresses, however, that pervasive changes will require restructuring societal values and priorities, quoting observation that "Education springs from the interplay between the individual and a changing environment . . . [namely through the links among] schools, colleges, universities, and the communities that surround them" (1974, p. 13). That is, through the interaction of the young in environments that form an ecology of achievement.

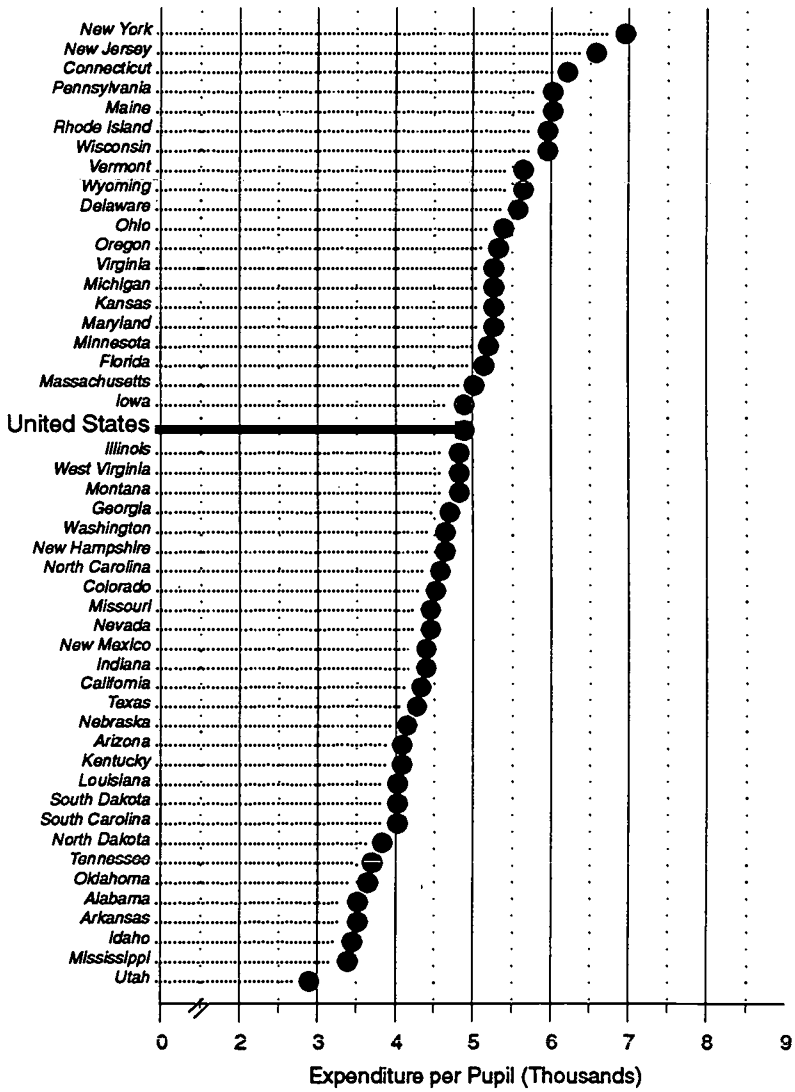
In view of the syndrome of the deficiencies of the teaching and learning environments whose recognition labeled the crisis late 1970s, it is not surprising that the *National Assessment of Educational Progress* continues to report deficiencies in science achievement (as measured by its criteria) as well as a fall-off in effective programs (National Center for Education Statistics, 1991a).

In 1993, the National Science Board summarized the Educational Testing Service's trend analysis of the results of the 17-year mathematics and 20-year science *National Assessment of Educational Progress.* Although mathematics achievement seems to be generally improving, the summary shows ups and downs in science that do not reveal a clear pattern. For example, the average mathematics proficiency scores for 9-year-olds showed gains since the 1970s, especially between 1982 and 1990. Seventeen-year-olds decreased their scores between 1970s and 1980s "and then by 1990 regained the ground they had lost" (p. 4). The average proficiency scores for "students at age 17 continued to drop until 1982—a 22-point drop over the period—then regained some ground. Their scores in 1990 remained still significantly below the 1970 level (15 points)"(p. 5).

Inequality in Funding

Underlying practically all analyses of the effects of limiting environments in schooling is the matter of resources, namely funding. Resources and materials are especially crucial in science where laboratories, equipment, and perishable materials of instruction play an essential part. This sets aside, for the moment, the need for teachers well-educated in various disciplines—biology, chemistry, physics, geology, space, and environmental sciences.

The Educational Testing Service study (1991) from which the figures reproduced below are taken not only points out inequality in funding but also strongly implies that undersubsidized programs are unlikely to help students reach optimum levels of achievement. That study, *The State of Inequality,* shows that, in 1989-1990, the average per pupil expenditure (adjusted for cost of living) ranges, in the top 14 states from $5,000-$7,000, to, in the bottom 14, from $3,000-$4,000. The ratio of differences in 1986-1987 between high and low average expenditure per pupil shows that some states spent as much as three times as others. (See Figure 1.)

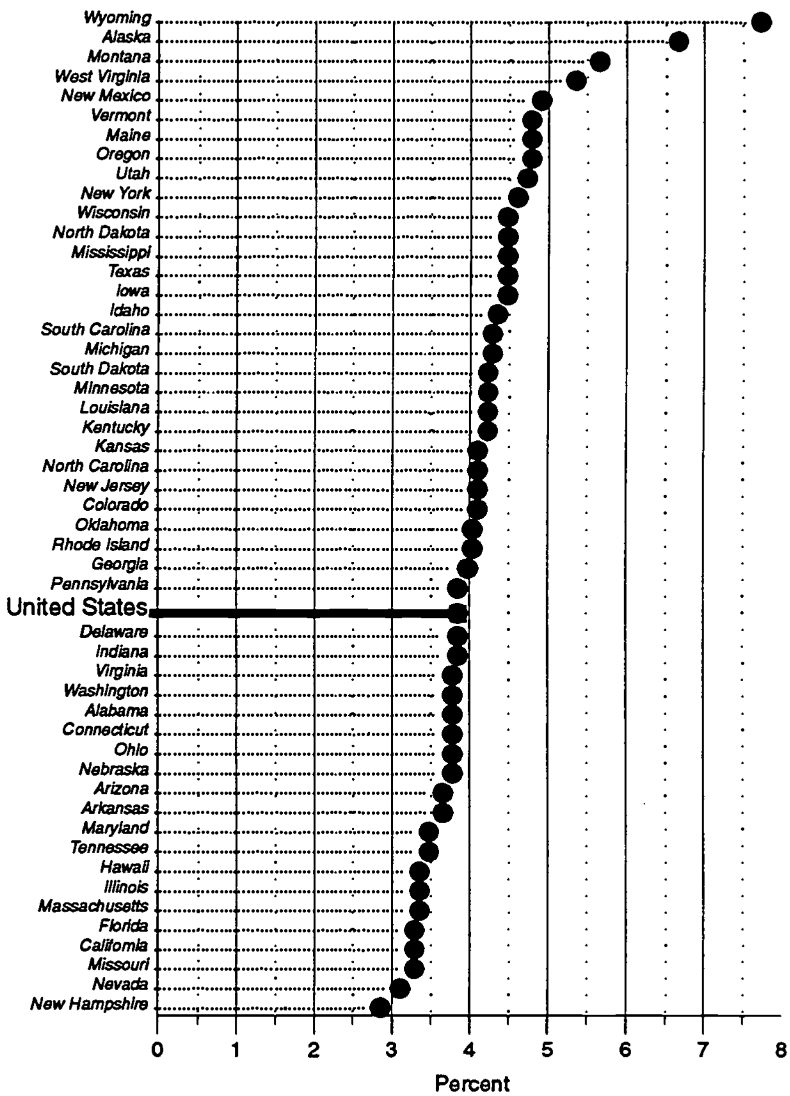


Note: Adjusted expenditures are unavaliable for Alaska and Hawaii because of unique factors involving climate and transportation.

Reproduced with permission from *The State of Inequality*, Policy Information Center, Educational Testing Service, 1991.

Figure 1. Average Expenditure per Pupil, Adjusted for Cost-of-Living, 1989-90

But the 1988 education expenditures also vary when they are computed as a percentage of personal income: For example, Utah, low in average pupil expenditure is near the top in expenditures of personal income. (See Figure 2.)



Reproduced with permission from *The State of Inequality*, Policy Information Center, Educational Testing Service, 1991.

Figure 2. Education Expenditure in 1987-88 as a Percent of Personal Income in 1988

And funds are not unequal merely state by state. They also vary district by district, county by county, and school by school.

The differences in expenditures in a number of states, cities, and districts are related to the availability of resources for study in science and mathematics—laboratories, equipment, and other instructional materials, replacement textbooks, funding for field trips, and the like. Different expenditures also affect the teacher-student ratio; in one state it varied from 13 to 30 students per teacher depending on the wealth of the district. In some states, average salaries (rounded) for teachers ranged from $28,000 in the richest districts, to $22,000 in the middle group, and to $20,000 in the poorest areas.

The Educational Testing Service (1991) study recounts events in a number of states, particularly Kentucky, where differences in funding were found unconstitutional by state courts. In compliance, Kentucky instituted funding reforms to assure not only equity, but also to improve practices to reform curriculum and instruction. Some states, however, are contesting court directions to achieve fairer funding. The Educational Testing Service notes that, "So far the national education reform movement has not directly addressed the wide disparities in resources applied to educating America's children and youth." It wonders, "For the year 2000, will a student be considered an educational citizen of just a school taxing district, or of a whole state, or of a nation?" Litigation on this and related matters is ongoing in 21 states, and "it is hard to predict where it will take us by the year 2000" (pp. 20-23). In an attempt to correct glaring inequities in funding among school districts resulting from education's property tax base, (some of them described in Kozol, 1991), Michigan has abolished this base and is experimenting with replacing the lost $6 billion by levying other kinds of taxes.

An Initial Effect of Inadequate Resources

Other parts of the Educational Testing Service's study, such as one of the resources available to teachers of eighth-grade mathematics, asked how well they were supplied by their "school system" with the "instructional materials and other resources they needed to teach their classes." The study reports that, as teacher perceptions of the inadequacy of resources increased, proficiency scores decreased (p. 14). Gaps in the ecology of achievement? The Educational Testing Service quotes the *National Assessment of Educational Progress,* however, as asserting that assessments of instructional resources are less likely to be available in poor districts and disadvantaged urban districts (1991, p. 2).

The presence and use (or their lack) of computers are critical indicators of adequate resources because computers are essential in the postindustrial ecology of education, particularly in schooling. At the moment, according to a 1993 survey by the National Education Association, classrooms "lack the most basic technologies found in office environments" (p. 1). Only 12 percent of teachers even have *telephones* in their rooms, and although, 90 percent have "access" to computers, only 52 percent have one in their classroom. The summary continues: Teachers at more affluent schools had access to a modem, unlike 36 percent of teachers in middle-income and 30 percent of teachers in low-income communities (pp. 1-2).

About three-fourths of the teachers surveyed saw tight budgets as the reason they could not make better use of technology. Other obstacles include lack of

- training (53 percent)
- software (48 percent)
- technical support (46 percent)
- sufficient wiring (37 percent)

The survey also reported that the richer schools are more likely to provide a "high-tech environment" than the less affluent and that nearly two-thirds of teachers use mimeograph or ditto machines rather than photocopiers. Nonetheless, about a third of teachers (and half of those in high-tech schools) believe that their teaching effectiveness has improved "very much" because of technology.

Gender Discrimination

A 1992 study for the American Association of University Women's Educational Foundation concludes: "We can no longer afford to disregard half our potential scientists and science-literate citizens of the next generation." Among other data, the study cites a finding that "64 percent of the boys who had taken physics and calculus were planning to major in science compared to only 18.6 percent of the girls who had taken the same subjects." The implication from studies cited is that "girls rate teacher support as an important factor in decisions to pursue scientific and technological careers" (all quotations, p. 4). Oakes (1990) offers further evidence of gender discrimination.

A 1994 issue of *Science* containing a special report on issues confronting women in science internationally (unfortunately, few comparative data have been collected) offers "a beginning" discussion and "some surprises" (Benditt, 1994, p. 1467). Among the latter is the relatively good experience of women scientists in Italy, Portugal, Turkey, and the Philippines compared to those of their colleagues in the United States, Great Britain, Germany, and Japan. One important aspect of the Italian experience could have useful implications in schooling in this country:

> Tradition[5] is helpful, . . . but it is not the decisive factor. A more powerful influence . . . is the Italian system of schooling. "Girls are not discouraged from taking math and science," says nuclear physicist [Francesca Bombarda]. In fact, she says, "we never got the choice." In Italy, high school girls don't have the option of dropping out of math and science—and thereby foreclosing a science career—because those courses are required for everyone. Bombarda says in Italy many girls who might not otherwise have considered a career in science develop interest during high school—at a time when many girls in the United States have long since stopped taking science courses. (p. 1481)

A recent publication by Orenstein (1994) in collaboration with the American Association of University Women also underscores the importance for U.S. females of having confidence in their mathematics and science skills. Females who succeed in these subjects do not seem to devalue their abilities during adolescence as, the study documents, do most of their peers.

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[5]In a "key historical work," *Women in Science*, Mozans (1913) noted that:

> Italy boasted a history of female intellectual achievers dating back to the middle ages. Women were allowed to attend the first Italian universities from their inception during the Renaissance.
> From those universities emerged a handful of acclaimed female academics, including a prodigy and mother of 12 children named Laura Bassi, who in the mid-1700s was awarded a chair of physics at the University of Bologna, as well as a place in the prestigious Academy of Science at Bologna. (p. 1480)

An Unrepresentative Teaching Force

According to figures analyzed by the Horizon Institute (1989), most elementary school teachers are women (who teach science along with other subjects), and most high school science and math teachers are men, although the 1970s and 1980s saw a substantial decrease in the proportion of male science and mathematics teachers. And, while about 30 percent of students are minorities, less than 15 percent of their science and mathematics teachers are. By the year 2000, however, approximately half of the student population will be members of minority groups, according to the Task Force on Women and Minorities in Science and Technology (1988).

Given the changing demographics of the student population and of the teaching force in general, the underrepresentation of minority science and mathematics teachers may become more severe, and the result is likely to be a scarcity of teachers with whom the young have affinity in gender and race.

Underpreparation of Elementary School Teachers in Science

Research shows that children spend little time in elementary school learning science (factor 10 in the Syndrome). For example, Tressel (1988) stated flatly: "For all practical purposes we do not teach any science in elementary school; one hour a week doesn't count" (p. 2). Tobin and Jakubowski (1989) criticize the use of lecture, noting that "knowledge is piped from the teacher to the student." There are a large number of studies of the generally inadequate state of elementary science teaching in the 1970s and 1980s, including Brandwein (1981, 1987), Duschl (1983), Gabel and Rubba (1979), Gerlovich, Down, and Magrane (1981), Manning, Esler, and Baird (1981), McNairy (1985), Mechling (1983), Shrigley (1974, 1976, 1977), Westerback (1984), and Walsh and Walsh (1982).

The condition is serious. Among other researchers, I put forth the concept that early instructed learning can offer children opportunities to identify their interests and possibly influence future choices. (See Brandwein [1987] and Construct III of this study. Also consult the National Science Board *Indicators* [1993] [pages 43-44]; Murphy [1961, p. 139]; Rakow [1985, p. 154]; Roeper [1989], the *National Assessment of Educational Progress* reports [National Center for Education Statistics, ca. 1972-ca. 1992], and the National Education Goals Panels Reports [1991-1994].)

The effect of early instructed learning on children's aspirations is as applicable to science as to other fields. A course for primary school teachers organized by University of California, San Diego, biologist Paul Saltman sprang from concern about the situation in elementary school sciences. Taught by University research scientists and attended by 102 elementary school teachers, the course revealed both how important and how possible it is to make science happen early. When the course began in 1988, Saltman asked the teachers enrolled, "How many of you had one year of college science before beginning to teach?" Eight out of 102 raised their hands. These teachers were avoiding science, teaching it an average of 20 minutes a week, and expressing their "loathing and fear" of the subject. Three years later, after the laboratory experience in science that Saltman organized with the help of his colleagues, the teachers were offering an average of 40 minutes of science each day. Saltman attributes this change to an increased "comfort zone of knowledge." The Washington, DC-based National Science Resources Center is thinking of widening the Saltman project nationwide (Barinaga, 1991).

Low-Income and Minority Students

Oakes, Ormseth, Bell, and Camp (1990), in a study primarily based on the National Science Foundation's cross-sectional data gathered in the National Survey of Science and Mathematics Education, conclude that the learning of low income and minority students is hampered by many factors:

> In addition to attending schools with less extensive and less rigorous science and mathematics programs, less-qualified teachers, fewer resources, and less engaging classroom environments, low-income and minority students often find themselves in low-track classes that focus on "general" mathematics and science content and provide less access to the topics and curricular objectives that could prepare them for successful participation in academic courses in these subjects. (pp. 104-105)

Erich Bloch, former director of the National Science Foundation, noted the relation of underrepresentation[6] to limiting environments:

> Underrepresentation raises important concerns. The first is whether or not these groups have the same access to education in science and engineering fields as the majority. The second is whether underrepresented groups with requisite education have similar opportunities in science and engineering employment. Differing experiences may result for several reasons including differences in socioeconomic characteristics, career preferences, or a combination of factors; they may also result from inequitable treatment. (National Science Foundation, 1990, p. iii)

The same report notes that lower performance by these groups in mathematics and science emerges as early as the elementary school level.

Even now, most high schools with programs for the science prone test students for admission as if *all* had similar antecedent schooling in English, mathematics, and science. Others with such programs use entrance examinations centered in English and mathematics and practically devoid of science; this practice seems to acknowledge that many students' schooling in science prior to high school is inadequate. They may also be poorly trained in English, and the fact that some of them are at home in another language has probably been treated as a weakness rather than as a strength.

In sum, in teaching and learning, what is not *open* to children early on may be *closed* to them later.

Declining Interests, Differing Destinations, Changing Demographics

American men's interest in science and engineering Ph.D.s is apparently declining; the recent increases in the workforce in science are due to higher entering numbers of women and foreign citizens. In 1980, according to Burke (1992), U.S. citizens earned 84 percent of all doctorates; by 1991, only 66 percent went to citizens. Government-University-Industry Research Roundtable figures show that foreigners on temporary visas

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[6]Equitable representation of various groups within a scientific profession generally means parity within the work force or within the population as a whole. Although females make up more than half of the population and minorities, about a third, they make up only small percentages of the science, engineering, and technology workforce--overall only about 16 percent of scientists and engineers are women, and under 10 percent are nonwhite. Thus, both groups are underrepresented in science and engineering.

now earn more Ph.D.s in engineering in the U.S. than U.S. citizens (1987). In the natural sciences, the dependence is also substantial—20 percent of Ph.D.s are earned by temporary visa holders (p. iv). It is now commonplace for foreign citizens to take the places vacated by Americans. Visa holders as well may enter the workforce. But there is no guarantee they will remain (National Science Foundation, 1990). Burke reports one estimate that half of foreign students remain here to work. In addition, the Bureau of Labor Statistics forecasts that, over the next decade, civilian employment of scientists and engineers may grow by 40 percent (Roundtable, p. 3).

Numerous sources, including the Roundtable and the National Science Foundation, project that the number of 18-24-year-olds is expected to drop before the end of the century (in 1987, the Roundtable estimated a 25-percent decline). If the United States graduates fewer baccalaureates in science and engineering fields and reduces the number of participants in postgraduate studies, the results could affect the nation's postindustrial achievements and the availability of "human capital." Note as well, the most severe teacher shortages are in mathematics, physics, and chemistry (Akin, 1986).

Constructs III and IV will probe exemplars of enabling ecosystems that aim to fashion ecologies of achievement that nurture the science talented. The earliest years of the present K-12 program constitute a hit or miss approach to elementary and middle-level science, strong in a number of schools, modest in the average ones, and wanting in most. Its development is urgent: The Roundtable's (1987) analysis of a number of disturbing trends concludes that the time prior to sophomore year in high school is critical in recruiting students to the science courses that will prepare them for baccalaureate-level science study.

The failure to earn a baccalaureate in a science field or enter such a profession may imply either inadequate preparation or a change in career direction or both. In any event, the result is a fall-off in young preparing for a profession in science. Is this fall-off solely the responsibility of the student? Of the schools? Or is it shared by a flawed ecology of education? Some alternative enabling ecologies of *achievement* will be described in Constructs III-V.

Science and Engineering Talents: Representation, Range, and Recognition

MacKinnon (1978) suggests that talent is to be confirmed in an occupation. He defines talent as "a complex of traits which qualify one for superior performance in some occupation, or more typically, some profession" (p. 23). Feldman's developmental model (1986) also attends to the talented individual's eventual performance as an adult. So too, does Renzulli's triad, which stresses performance expressed in a product (1977), and Sternberg's triarchic model, which notes the shaping of real-world environments in managing a career (Wagner & Sternberg, 1985).

The following data, largely taken from the National Science Foundation's 1990 study, offer a sense of the range of the science occupations that presuppose a talent in a subset of the field. They also indicate, in a general sense, the individuals who are going into science and engineering. These data should be useful to teachers, particularly in their roles as mentors.[7]

[7] The analysis relies primarily on 1976<N>1986 data (National Science Foundation, 1990) not only because they include estimates of male and female representation but also because 1976-1986 and 1978-1988 data tend to be mixed in estimates of the scientific workforce. Also, the 1976-1986 data were survey-

During the years between 1976 and 1986, more than 70 percent of the new growth of 1.8 million professionals in science and engineering fields occurred in business and industry. In industrial employment, scientists increased at an annual rate averaging 8.3 percent over the decade—one-half the total U.S. increase in scientists. Engineers in business and industry increased by 6.5 percent annually, accounting for almost 90 percent of the U.S. employment growth in this field. Over this decade, approximately 29 percent of all scientists and 4 percent of all engineers were employed in educational institutions. In business and industry, the proportion of Ph.D. scientists increased from 20 to 27 percent; doctoral engineers rose from 51 to 55 percent.

Women

Although women made substantial gains in science and engineering employment during 1976-1986, they remain underrepresented in the science and engineering workforce. Employment of women computer specialists increased sixfold during this period, however, from 21,000 to 128,000. By 1986, 24 percent of women scientists and engineers were computer specialists. At the same time, the number of women in engineering quadrupled, growing at an average annual rate of almost 16 percent. Employed female social scientists increased by only 65 percent during this decade, much less than the 200-percent growth of women in science and engineering fields overall. Because of this slower growth, the proportion of women social scientists declined from 31 percent to 18 percent. Recent 1992 National Science Foundation figures, however, show them to have increased their numbers to 50 percent (1994, p. 3).

According to Natalia Meshkov (1992) of the Argonne National Laboratory, because of the shortfall of scientists and engineers, "Attracting women to science is no longer just fair, it is now also necessary" (p. 19). Nonetheless, the National Research Foundation shows them in 1992 as making up 22 percent of the science and engineering workforce (1994, p. 3).

Minorities

In a special section of *Science* devoted to "Trying to Change the Face of Science," Culotta summarized some of the difficulties faced by those "people and organizations . . . throughout the scientific enterprise . . . trying to add color to the mostly white face of science and engineering. As the number of Ph.D.s earned by foreign nationals is rising," she continued,

> U.S. minorities continue to earn a tiny proportion of science and engineering Ph.D.s—5.9 percent in 1992. Furthermore, although Hispanics have increased their representation, the bulk of the increase in minority Ph.D.s is due to gains made by Asian Americans—whose status as an underrepresented group is a source of much debate. (1993, p. 1089)

In science and engineering fields, African Americans are underrepresented, accounting for 2.2 percent of the scientists and engineers employed in 1986; however, Black employment in these fields increased much faster than that of Whites in the 1976-

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generated; the 1988 data were model-generated. Where 1988 data appear in the following account to support the generated trends, they also support the 1976-1986 data--and possibly the trends in the next years.

1986 decade: 9.7 percent versus 6.2 percent average annual growth (National Science Foundation, 1990, p. 22).

Native Americans were somewhat less than 1 percent of workers in science and engineering fields, which is roughly similar to their presence in the overall U.S. labor force. Hispanics are underrepresented in science and engineering fields, making up approximately 2.1 percent of scientists and engineers in 1986. Roughly 6.6 percent of all employed persons were of Hispanic origin; about half of these were in professional and related occupations.

In contrast, Asians were almost 6 percent of all scientists and engineers, while they were less than 2 percent of the U.S. labor force and 3 percent of those in professional fields.

Foreign Students

According to the National Science Foundation,

> In 1972, the number of science and engineering doctorates awarded in the United States peaked at 19,000, then declined steadily until it leveled out at 17,000 in 1978. Since then, however, the number . . . has increased almost annually: In 1988, roughly 20,300 science and engineering doctorates were awarded, representing 61 percent of all doctorates. . . . All of the growth in the number of science and engineering doctorates awarded since 1978 is accounted for by rapid increases in the number of foreign graduate students receiving such degrees. The number of U.S. citizens receiving science and engineering doctorates has declined somewhat since 1978. (1990, p. 37)

Culotta, writing in the special issue of *Science*, summarized: "From 1975 to 1992, the share of all scientific and engineering Ph.D.s earned in the U.S. by white citizens dropped from 70 percent to 56 percent, and there was a concomitant rise in doctorates earned by foreign nationals" (1993, p. 1089). Other sources recount a somewhat different trend. During the past decade, American students slowly increased their participation in graduate education, as students from abroad dramatically increased theirs, especially in programs in mathematics, physics, and computer science. While foreign students accounted for 20 percent of the total graduate enrollment in science and engineering in 1983, they accounted for 26 percent of the same field in 1990 (National Science Board, 1991, p. 58).

Foreign students made up 28 percent of graduate enrollment in mathematics in 1983, a figure that rose to 32 percent in 1990, but this is negligible compared to their increased enrollment in computer science, which jumped from 23 percent to 31 percent in the same seven-year period (National Science Foundation figures, p. 143, Table 42; p. 147, Table 46).

According to Burke,

> While the proportion of foreign students overall in science and engineering has increased, certain fields have experienced greater growth than others. The most pronounced growth occurred in the physical sciences, where the number of foreign Ph.D.s increased 163 percent from 962 in 1980 to 2,529 in 1991. During the same period, the number of foreign Ph.D.s in engineering increased from 1,185 in 1980 to 2,850 in 1991, a proportional increase of 141 percent. (1992, p. 3)

In the past, changes by individuals moving to another subset of scientific occupation and increasing reliance on foreign-origin personnel have been largely responsible for the supply/demand equilibrium in the science and engineering supply. National Science Foundation data (1990) show that native-born citizens declined from 90 percent in the science and engineering workforce employed in 1972 to 83 percent in 1982. According to Burke, "The cumulative result of changes in the world order and in our immigration policy has been to increase significantly the number of qualified scientists and engineers competing for a diminishing number of available positions" (p. 2).

The Situation Ahead

Falling numbers of young entering college with the intention of preparing for a science profession in this decade, as well as the generally declining college-age population, has already resulted in fewer baccalaureates (and, therefore, fewer scientists and engineers). The ranks may be filled partially by older students and foreigners, many of whom remain to work in the United States. There will be more female science and engineering graduates and a broader ethnic mix. In addition, small shifts in the percentages of students electing to train in science and engineering fields and in the proportions of graduates who choose to enter science and engineering employment could provide an adequate supply of new entrants to the science and engineering workforce.

There are other possible adjustments. The mobility of the labor force is particularly important in instances where tight markets and circumstances may dictate that veterans leave their current specialties and transfer to new fields. (Such a pattern may explain how the high demand for computer specialists was at least partially met.) Also, in spite of high unemployment in certain specialties, fewer people trained in science and engineering may be willing to accept unspecialized jobs. There may be self-imposed delays in retirements of science and engineering workers. Finally, and particularly usefully, employers may provide training and upgrading of their technicians.

Further research is necessary, however, to determine whether the formerly widely predicted shortfall among science, engineering, and mathematics personnel will occur, and if so, how serious it will be. In the early 1990s, reports the National Science Foundation (1993):

> The recession, defense-related spending cutbacks, reduced research and development budgets, and industry downsizing all took their toll on science and engineering employment. Manufacturing science and engineering employment declined for the first time in more than a decade; unemployment rates rose; entry-level salaries stagnated; and overall salary growth did not keep pace with that of other professional occupations. Despite these trends, scientists and engineers have fared better than almost every other kind of worker. (p. 61)

Talent or Talents?

The subsets of characteristics making up a "scientist" do not point to a single field of human activity requiring a clearly defined talent. "Science talent" is overall a convenient designation, finally demonstrated in a variety of active characteristics appropriate to a final career choice. Different scientific fields obviously require different bases in graduate knowledge and inquiry.

Among the categories of scientists analyzed by the National Science Foundation's report are

- physical scientists, including chemists, physicists/astronomers, and others
- mathematical scientists, including such subsets as earth scientists, oceanographers, and atmospheric scientists
- life scientists, including biological, agricultural, and medical scientists
- social scientists, including economists, psychologists, sociologists, anthropologists, and others
- engineers, including aeronautical/astronautical, chemical, civil, electrical/electronics, industrial, materials, mechanical, mining, nuclear, petroleum, and others.

Different specialties seem to require different training and flourish through the play of different skills and talents. The talents of environmental scientists and those of astronomers require different modes of expression in training and research. The substance and types of inquiry in their domain-specific areas are recognizably different.

Gagné (1985) has defined giftedness "as exceptional competence in one or more domains of ability, and talent as exceptional performance in one or more fields of human activity" (p. 111). I would add that science talent is both a general category and an amalgam of personal traits and abilities focused in specific fields such as those mentioned above. While giftedness is general, talent comprises the specific aptitudes required for the subsets of a field. Individuals with various talents and exceptional competence can begin to make significant career choices even during precollege and freshman years.

Before Eminence: Novice Scientists and Artisans, Hidden Collaborators in Discovery

De Solla Price's essential thesis on the nature of scientific civilization (1961/1975) is relevant to these observations. In discussing discoveries by prominent and eminent scientists who are often heads of research cadres, De Solla Price notes that "Probably it follows that to double the population of workers in the few highest categories, there must be added eight times their number of lesser individuals" (p. 120). "Lesser individuals" is perhaps an unfortunate choice of words for persons who may be assistants in research, novice scientists with new Ph.D.s, or contributing scientists in a particular field. Among them can be individuals who prepare the ground in complementary but subordinate positions in originative investigation but are not yet foremost in recognition.

There is as well a range of talents in the "invisible college" (also de Solla Price's idiom), a group of scientists bonded in work and friendship who communicate well and thus may aid each other in various ways in reaching the point of discovery. In addition, assistants in the laboratory create and supply equipment and materials to the order of the research scientist.

For example, Rabkin (1987) described a vital task in spectroscopy, presumably performed by "lesser individuals"—possibly novice scientists or artisans. Hundreds upon hundreds of individuals, probably unacknowledged in the final conception, may have used the instruments and contributed masses of data and facts resulting in—and making possible—analyses and syntheses by a representative body of scientists. Nonetheless, in the familiar shorthand of printed space and passing time, only a handful of eminent scientists are given credit for prominent discoveries in spectroscopy. Rabkin pointed out that

> Among the most important new methods was infrared spectroscopy, which acquired remarkable popularity during the 1950s and 1960s. The number of infrared instruments, a handful before the war, rose to 700 in 1947, to 3,000 in 1958, and to 20,000 in 1969. The technique's use in scientific research, as recorded in a 1965 report issued by the National Academy of Sciences in Washington, DC, skyrocketed correspondingly. (1987, p. 31)

For recognition in achievement in science, beginning scientists need the *intellective and nonintellective factors and environmental facilitators* to grow into giants in the eyes of their colleagues and the media. They also need to choose proper fields—ecology and environmental science, for example, although critical sciences in the years to come, are not yet the road to the Nobel Prize. To emerge from the statistics of the larger group of scientists often requires luck in the past and prospective environments. In general, to nourish a gift or gifts into a talent or talents, requires a gifted environment—and the wisdom to benefit from it.

Perhaps, the family-school-community, college-university, and cultural ecosystems would contribute to the brilliance of the world if, in their interconnectedness, they would lend their collaborative resources to all young who aspire and are capable of achieving. Then, students who acquire the trained intelligence—in whatever capacity—desiring to enter the sciences prized in the United States would fulfill their powers in the pursuit of excellence. And, as they shaped their own opportunities, they would begin to define their self-concepts as well. They would know, from the beginning, that the massive achievements characterizing scientific research generally result from the works of scientists in all categories: From artisan to novice to eminent scientist.

Artisans: As Contributors to Research

Passow's paper on "The Educating and Schooling of the Community of Artisans in Science" (1989a) summarizes our need for "the fullest development of individual potential and the nurturance of specialized talents to fill the need for creative, imaginative, productive individuals" (p. 27). If we visit laboratories, we find such contributors of specialized abilities to the research teams—namely, artisans at work in their various crafts. A society depending on science and technology rests in great part on their contributions.

Certainly in "big science"—for example, the Manhattan Project; the Superconducting Super Collider (currently suspended); the space projects (telescopes, weather satellites, and the like)—the crafts at which artisans excel are of superordinate need. Postindustrial laboratories large and small use artisans trained in different fields of science to do research. Timpane (1993) notes the presence in different fields of science of graduates at all levels performing functions basic to the technology or research teams working in "pure" science. Science careers for non-Ph.D.s are part of the picture.

More often than is recognized, a technique may revolutionize a field. The scanning tunneling microscope Binning and Rohrer invented in 1982, and for which they received the Nobel prize, has "a half dozen spinoffs—among them, the atomic force microscope which has demonstrated how molecules of fibrin join to form a blood clot, and the magnetic force microscope which can be used to detect the magnetization of patterns of computer hard disks and floppy disks" (Hall, 1992, p. 349). These developments required the trained intelligence of the eminent *and* contributions from the middle ranks, novices as well as artisans.

Not only in great discovery but in everyday experiment, the talented artisan is part of the team. Hall (1992) quotes the astrophysicist Patrick Thaddeus, "Behind every great discovery in astronomy, there's a guy with a soldering gun," his metaphor for artisans' varied and essential skills. The eminent scientists who know how to organize the multitude of basic researchers into a burst of discovery are precious indeed, but they do not work alone. Science talent in artisans is prized by the theoreticians and experimenters who appreciate their contributions. And once in the laboratory, the talented artisan may undertake advanced study as the possibilities evolve.

For schooling and education, the concept that talented technicians are highly important to a research project means the necessity of an ecology of achievement embracing a wide approach to curriculum, instruction, and laboratory practice. It also means that such an ecology, by its very existence is open to tempt *all* young with various science talents to pursue their special excellences.

Construct II Implications

The mutualism of the three human ecosystems acting within an ecology of education in intereffectiveness is, however, not a matter of course. Because they act within a total framework, their interaction is generally not mandated but lies within the sphere of choice, except when a specific function is dictated by law. No matter; their acts in support or neglect affect the totality of American education and thus intereffect within an ecology of achievement.

Nothing in this study calls for a curricular and instructional experience composed of a stable set of experiences to fit all abilities and predispositions, thus attempting to ensure a steady progression through the grades. Quite the opposite, this study presses the invention of programs that encourage *differences* in expression and performance, and the inclination to seek special excellences and worthwhileness through a family-school-community program. In this sense, the limiting ecologies discussed in Construct II can stand in the path of the expression or attainment of desired abilities.

When barriers, such as limitations in instruction as summarized in the syndrome of 10, inadequately prepared teachers, and inadequate funding, combine with other factors to prevent the creation of an ecology of achievement, the results can be serious. Their consequences in the wide educational environment—especially the socioeconomic conditions affecting home, family, school, and community—can contribute to a reduced supply, first of young with interest in science and then of scientists and artisans.

Women and minorities, though making some headway currently, are particularly affected. The fall-off continues through misuse of what the Roundtable called the "weed and seed" approach in many of the nation's college-university ecosystems (1987). The National Science Foundation, along with other institutions concerned with the fullest representation of contributors in science, finds the origin of the present underrepresentation in early schooling, particularly in inadequate preparation in science and mathematics.

Granting that some young take the challenge of limitation and overcome it, research emphasizes that supporting environments, particularly those from early childhood through the grade school years, are generally necessary to prepare the young for the course they take in securing competence and performance.

This study aims to define an environment in schooling and education designed to encourage self-identification and self-selection of science prone and science talented young.

This ideal was and is a necessary intervention (or invention), since the ecologies of both school and culture intereffect the development of abilities and predispositions, thus attempting to ensure a steady progression through the grades.

An ecology of achievement—see Constructs III and IV—allows the intermeshing relationship of heredity and environment to encourage the full, direct expression of talent, whether in science or in another area of value in human and humane prospect. First, however, these data give rise to certain important assumptions. They follow:

1. Almost all American and foreign immigrant young who will become scientists in the 21st century are presently in our schools.
2. It is apparent for the present and possibly for the near future that a sufficient number of American young are unavailable to fill the need for the scientists of the future. Foreign scientists are now being trained here, but there is no guarantee that they will not return to their countries of origin.
3. The frequent premise that the thrust of practice in curriculum and instruction for the science talented should aim at the apex—the research scientist—requires reexamination. A visit to almost any research laboratory dispels the notion. All competent laboratories prize the contribution of skilled artisans and/or technicians. Practices in guidance and during early schooling as well as programs should be developed for those whose inclination is to artisanship. At present, the well-formed American system of community colleges makes available later opportunities for credentials in a variety of skills.
4. Stressing achievement and self-concept at the beginning of a career in science is as necessary as stressing the history of achievement of the eminent. The latter holds up a vision of greatness as stimulus, the former, the high probability of a worthwhile lifework (however hidden from public view) and a significant contribution.
5. This construct's emphasis on limiting factors brings to mind only half the case, only part of a human ecology: The environments that make up this ecology are not severable; seeming opposites interpenetrate and, eventually, a natural ecology heals itself. In the communicable human ecology, the significant factors of materials, energy, and information engage purpose and action to introduce enabling environments to offset and replace limitations on a productive ecology.

The enabling, favored environments in intervention and invention discussed and demonstrated in Construct III are intended to neutralize, offset, and replace the limiting environments characteristic of *flawed* educational ecologies.

Construct III:
Enabling Achievement—An Instructional Approach Designed for Self-Identification of Science Proneness

Construct I described basic factors undergirding an ecology of achievement, including the interdependent intellective and nonintellective qualities affecting endowment and opportunity. Construct II gave evidence of some of the deficiencies of the family-school-community environments, deficiencies that hamper not only general education in science, but also the advance of science proneness that sometimes leads to science talent.

Construct III examines certain strategies and practices in teaching and learning that may sustain the contributions of scientists and science to culture and society. The literatures of developmental biology, psychology, and sociology overwhelmingly concur that the young's early experience and development are prologue to later aptitudes, opportunities, and destinations. Early deprivations in science and mathematics literacy resulting from deficiencies in instruction, along with other limiting factors, seem to lead to later underrepresentation in the science professions.

Construct III searches for models of teaching and learning enabling expression of a leaning toward science in the primary school years: First, through examination of theoretical constructs, from which are drawn clues to instructional practices that help to identify and define early science proneness; and, second, through study of practices of science instruction that encourage children to identify themselves as science prone and demonstrate their awareness prior to high school. The clear purpose: To ameliorate, if not to annul, the syndrome of 10.

A Proposition on Direction

This study postulates that a structured environment in science, framed in Margaret Mead's "constructive affection" and coupled with students' ability to succeed in originative inquiry along with notable acquisition of knowledge can be—and has been—a valid index of early expression of science talent. Further, early science proneness is best understood in an expression in field-specific talent (Feldman, 1982, 1986; Wallach, 1976).

As noted in Construct I, IQ scores per se do not seem to predict expression of science talent. Ward (1975) noted two modalities of giftedness—general intelligence defined in IQ scores and specific aptitudes (or talents) as measured by valid tests.

A Combined Effect

Discussions by life and physical scientists, psychologists and social scientists, and school and college educators during the curriculum reform period (1958-1960) led to this general proposition: The function of science education is to create an environment optimum in opportunity for achievement in its fields by students in the schools and in colleges and universities. The present era of research and practice makes clear that intervention in schooling and education should in great part be within the domain of changing environmental mechanisms. This thrust may change in scope as the human genome studies proceed. Current reformers, however, generally try to fashion environments in instruction and curriculum that favor the interaction of heredity and environment to produce the best expression of the human phenotype. The combined effect of this joint search obliges that the family-school-community, cultural, and college-university ecosystems should strive to invent curricular and instructional devices congruent with its mandate. By casting a wide net for excellence and equity, the family-school-community ecosystem can enable the search for and by the young for competence in general or specific performance in science. A significant improvement in science teaching may empower a larger pool of talent than selection based on IQ alone.

Tannenbaum notes "that childhood is usually too early in life for talent to be full-blown, so it is necessary to settle for talent-in-the-making and to keep in mind the uncertainties of the future" (p. 50). He continues,

> Because there is no foolproof, formal test procedure to identify budding research scientists, the best alternative is to engage seemingly qualified children in laboratory activity, including some kinds of experiences left out of the regular science curriculum. Those with potential in science would then be those who respond most successfully to the special challenges. Such straightforward procedures, practiced frequently and with gratifying results in the arts and in sports, are unaccountably ignored in many other talent domains that are of interest to educators.
> Not only should the gifted be identified and then educated, they should also be identified through education. In other words, prescribed enrichment becomes a vehicle for identification as much as identification facilitates enrichment, the relationship now being reciprocal. (1989, p. 50)

In short, well-constructed curriculums and beneficent instruction may serve as identifiers of science proneness.

The operational approach I developed took a similar path (1955/1981, pp. 16-23). This program, for 10 years in the 1940s and 1950s, gave students the opportunity to do science in the scientist's manner "to all who desired it without pretest" (Brandwein, 1992, p. 122). Generally speaking, students who planned to make science a career could apply; those students who had shown ability in science (that is, who had already been instructed and had done work in science) were "invited" (p. 16). These data sustain Tannenbaum's (1989) and Borland's (1989, pp. 114-117) theses. The work of young in a program that sustains science proneness may indeed help identify promise for science talent.

Enabling Expression Before the Talent Pool Develops

Little if anything refutes the overwhelming conclusion of developmental studies that the interests, motivations, and predispositions in later development are laid down in childhood. On the other hand, Gallagher (1979) has warned that a negative environment may "reduce substantially" or even eliminate talent present early in the young.

Identification Through Instructed Learning

Many researchers have eloquently embraced the concept of the crucial importance of children's early environment. Bloom (1964) wrote, "First, the very rapid growth of selected characteristics in the early years; second, the importance of the sequential nature of much of human development; and third, the developments that take place in the early years are crucial for all that follows" (pp. 215-216).

Or, as Murphy (1961) put it, early on the child is engaged in "reality seeking"; striving to understand "reality exactly as a rationalist would seem to demand" (p. 32). Roeper (1989), grounding her remarks both in her experience with gifted children in the

Roeper School and Murphy's study, writes that the child's reaching out for new experiences is "exactly as a scientist would seem to demand. The child's laboratory is first home and then school," she continued (p. 122). Biber (1977) noted that, in early development, children progress as a result of direct exploration of their environment.

The Roundtable (1987, pages 37-39) also decided that the young are "lost to science" before the 10th grade. In part, this loss was laid at the door of instruction in early schooling. Terman and Oden (1954) discovered in their follow-up studies that early interest in science seemed to persist. In a study beginning in 1922, they had found that certain 11-year-old children who showed science proneness were still interested 18 years later as young adults; later, their choice of occupations also reflected science commitment.

Basing my thoughts on these concepts, I will try in the next pages to develop a model of instruction in science through which children may identify themselves as science prone. To illustrate, I will present a series of observations of science lessons that both demonstrate characteristic behaviors of elementary school young in various contexts and lead to self-identification of potential. My approach concurs with Havighurst's aim to design programs to meld with the potential of children early and so to increase the numbers of them who develop it (1972).

Schaffer (1980) noted that the "field of child development can contribute to the establishment of beneficial programs for gifted students by providing a rationale [for] a theoretical model stressing the developmental-interaction principle characterized by the child's reciprocal interaction with [the] environment" (p. 9). This theoretical model is crucial.

Curricular and Instructional Distinctions and Implications

The implication of these studies and others is that a curricular-instructional base promoting reciprocal interaction of child and environment is essential. Curriculum and instruction, as modes of promotion, invention, or intervention in learning, are used in this study as in Macdonald's (1965) definition as *relevant but distinct* fields. The structures of many curriculums, he said, confuse the two, which distorts the function of both in the learning process.

There are many reasons to redefine instruction and curriculum, among them their roles in promoting self-identification and self-selection of the science prone in particular teaching environments. *Curriculum* is a plan for teaching in classroom and laboratory; *instruction* is what happens in these environments, the field, or in independent study (at home or library) that stimulates learning through interaction between teacher and student. The objectives noted above call for a need to observe young in field research in "instructed learning" (Bruner's phrase, 1966). Later experience may, of course, alter expression and conduct in future development, as affected by genotype and environmental intereffectiveness. Children's early growth is affected by the caliber of instructed learning, and curricular and instructional provisions in science should help encourage science proneness, possibly into science talent. If differentiated programs are developed during the course of schooling, gifted young should have the opportunity to identify themselves early as science prone. Their path should be through personal activity in instructed learning and independent study available in a gifted environment, planned in curriculum and instruction that nurture science proneness.

At this point, formal testing is unnecessary either for self-identification by the young or as a means to prejudge their capacity. Assessment may, however, be used when the young present sufficient indication of varying capacity to acquire the correlation of observed behavior during instruction with measures developed to assist the judgment of the teacher. Early schooling, of course, should embrace a curricular and instructional program wider than science; that is, it should foster "many-sided intelligence" (Taylor's phrase, from Taylor & Barron, 1963) not only in the verbal and numerical instruction prerequisite to expression of science talent. Schooling should as well, obviously, include a wide range of opportunities for all studies.

Thoughtfulness, Foresight, and Understanding in Teaching and Learning in Science

Instructed learning in science presses for thoughtfulness in a search for understanding and foresight. All three are significant objectives in science (indeed in all scholarship), and their modalities necessarily interact in the curricular and instructional frameworks stressed here.

Bell (1973) meshes present and future scholars and teachers in his paradigm of knowledge making, which "consists of new judgments (research and scholarship) or new presentations of older judgments (textbooks and teaching)" (p. 175). When he was curator of the Agassiz Museum at Harvard, G. G. Simpson told me that he thought of science as an exploration of the material universe, in order to seek explanations of *testable* phenomena (1956-1957, see page 259). Conant (1947) saw a continuity in the nexus of new and old judgments and the explorations, explanations, and judgments of scientists. He embodied scientific foresight and understanding in defining science as a series of conceptual schemes, arising out of experiment and observation and leading to new ones. Thoughtfulness and contribution in science, thus, intermesh in a cycle.

Bell's definition of knowledge as merging *new* and *old* discovery (1973) is relevant to Schwab and Brandwein's distinction between "stable inquiry" based on *old* judgments, which permits guided discovery in the laboratory, and "fluid inquiry," which breaks ground in *new* understanding through originative probes (1962). Both stable and fluid inquiry are requisite in a curricular and instructional program planned to evoke the expression of science talent.

Degrees of Inquiry

Science textbooks and laboratory manuals hold up inquiry as an aim in instruction. Methods books used by modern science teachers in their pre- and inservice education also extol the principle of inquiry teaching and learning. So do science education journals and scientists' biographies. But whatever the rubric—inquiry, finding out for oneself, discovery, creative science, doing science, problem solving—there is a wide gap between problem doing with the conclusion foretold and ratified by direction in a manual or lecture and problem solving of an unknown. (On opportunities for the latter, see Constructs IV and V.) Nonetheless, the methodology of problem doing in lessons or laboratories can breed an atmosphere where the young discover things new *to themselves* through inquiry-oriented instructed learning.

When children engage in finding out, when they grasp something unknown to them, and when they then fit it within a concept, they are engaged to a degree in inquiry. Even though what they find is old principle to the experienced, it is new knowledge to them. When they begin the imaginative and innovative search in novel tasks and find their own path to something new, they are also engaged in inquiry, but of a much higher kind. They may be demonstrating science proneness.

And when such youngsters, now older and with a base in developed experience, engage in originative searches, they partake in a higher degree of inquiry, which may lead to a work, to the creation of new knowledge. They may thus express science talent (see Construct V).

This pattern corresponds to the degrees of inquiry of the three enrichment types that compose the revolving door identification model (Renzulli, Reis, & Smith, 1981). In brief, this model follows this pattern: If a student seems "gifted" (if, in Renzulli's definition, s/he has above average ability *and/or* task commitment *and/or* creativity) in regular classes, then, for a given period of time, that student is allowed to pursue a particular topic under the direction of a resource teacher. This topic can be part of any area of the curriculum—in the case of this study, on science. The student pursues the problem until the project is completed. At this time, s/he steps aside and makes room for another. Thus, the regular teacher and resource teacher work together to meet the aspirations of the gifted young. A resource person serves the student on the school level, in much the same way, according to Renzulli and his colleagues, "that a graduate advisor serves a doctoral student working on a research project." The ascending intellectual degrees of inquiry are also similar to Feldman's (1986) developmental views of stage shifts in domain-specific skills.

Instructed Learning and Inquiry: Theory as Model

A theory directs action; it should tell us when we are wrong and when we are right on a defined course of inquiry in both old and new discovery. In science, the prime characteristic of a general theory is that it usually becomes obsolete when a better one generates a new judgment (although, as Kuhn points out [1970], old paradigms can be tenacious). Gage (1963) and Bruner (1966) both discuss general theories of teaching; Bruner's *Toward a Theory of Instruction,* which defines the precise elements of a theory, is particularly applicable to inquiry in science.

Instructed Learning Applied to Science Lessons

Some time ago, I applied certain elements of Bruner's theory (1960/1979) to the conduct of a science lesson. In sum, the result:

> In any specified act of instructed learning, a new or altered environment is created from recognizable objects or familiar events so that learners respond by initiating activity involving the manipulation or transformation of the altered environment. As learners alter the perceived environment, they undergo changes in behavior as evidenced by their generation of verifiable orderly explanations of the changed environment, or as evidenced in the development of psychomotor, enactive, iconic, and symbolic devices, or models, assisting in the successful recognition or explanation of the object or event which is the objective of the specified act of instructed learning.
>
> Further, the environment in which instructed learning occurs embraces contingencies of reinforcement affecting both teachers and learners as increments in capacity successfully demonstrated by individual learners. (Brandwein, 1979, p. 291)

I meant Bruner's theory to lay a base not only for general practice in science teaching but also to serve as a prelude to a consideration of a form of instruction essential to any differentiated program evoking science proneness in young learners. Teachers and students in classrooms throughout the country tested this model of the science lesson, and it became clear that its utility lay in catalyzing idea-enactive, inquiry-oriented science teaching and learning.

Updated curriculums in science emphasize newer knowledge but, for all the protestations to the contrary, my research in 600 schools over a third of a century (see Cuban, 1979) show that the instructional mode generally remains embedded in apparently invulnerable lecture-textbook-recitations, at times modified by discussion. This is not to downplay the appropriate, even necessary, use of lecture when conceptual development requires it, but it is a system generally characterized by one-way communication from instructor to students. And, when used in excess by an inexperienced lecturer, it may be ineffectual because it is inclined to induce passivity in the learner and relies heavily on rote learning.

The Lesson as Index of Science-Prone Performance

Gardner's (1983) *Frames of Mind* developed a theory of multiple intelligences. Walters and Gardner (1986) noted that

> . . . in detailing the basic intelligences, multiple intelligence theory is careful to distinguish the "raw" or unmediated intelligence that predominates in children; the marshaling of that intelligence to various symbol systems, as evidenced in older children; and the adoption of a much more specific and focused domain of expertise by the adolescent or young adult. (p. 311)

As part of their study, Walters and Gardner interviewed teachers in mathematics, music, and the visual arts to learn "how the students performed during lessons" (p. 311). Their preliminary results show that children *may* learn to mediate their raw intelligence in the opportunities afforded by the idea-enactive, inquiry-oriented methodology of teaching and instructed learning. Through the opportunity to probe beyond the information given and thus to engage in personal and group experience in problem solving and concept seeking and forming during lessons, children sometimes begin a commitment to a focused domain, possibly science.

If giftedness is field-specific and demonstrated in a focused original work in a particular scientific area, then an inclination to science proneness may be inferred, as Walters and Gardner suggested (1986), from the action of the young in producing ideas and products during their lessons. Such behaviors may be found both in the examples of instructed learning detailed on subsequent pages and in the idea-enactive, inquiry-oriented behavior coming out of conceptual thinking. This behavior may be expressed in systematic assertions about observations made in the laboratory (in hands-on experience) or in ideas coming out of independent study. Thus, the behaviors of the young in science and in verbal and mathematical skills may well be an index of promise.

The hypothesis is that evocative instruction, stimulating idea-enactive, inquiry-oriented behavior consistently in the classroom, laboratory, or in individual work, may be used as a mode for the young early to identify in themselves a tendency to science proneness. And this self-definition may be followed by self-selection for further participation in differentiated curricular practice in science and in its supportive verbal and mathematical knowledge and skills. Because evidence of self-identification and self-selection of science proneness takes careful observation, the teacher becomes also a researcher and an interpreter.

The learner both responds to and acts upon the environment, in laboratory, in classroom lessons, at home, and/or through computer-assisted instruction. (When, in the 1930s through 1980s, I was observing lessons in the field and doing active research on a model enabling identification of science proneness through curriculum and instruction, however, computers were not generally available.) Assisted inquiry in instructed learning happens not only through hands-on activity but also through eyes-on, hands-on, brains-on, minds-on experiences. The examples of instructed learning to follow will show learners growing through observation and investigation, in psychomotor activities, in making images, in symbolic verbal and mathematical manipulations, and in transforming ideas (conceptualization).

In early schooling, these evidences of capacity may be taken as indexes of self-identification of science proneness; these traits may later, with perseverance, bloom into science talent. Early judgments are thus provisional—rightly so, in the interests of the further development of the young.

The lessons described here are examples from among the 272 I observed during the years 1938-1986 during field research to determine the modes of instruction prevalent in the elementary and middle school—periods of schooling crucial to evocation of science proneness. On the other hand, more than 221 other lessons I observed, particularly in middle and senior high schools, were of the lecture-demonstration-recitation type. (One hundred and twenty-seven, however, began to introduce science prone young to acts of originative inquiry).

Identifying Science Proneness: Field Research—Three Idea-Enactive, Inquiry-Oriented Models

Following are several examples of idea-enactive, inquiry-oriented teaching and learning in selected classrooms. In a sense, if successful, the children's understanding in science grows as does a plant: The seed is sowed and nourished (both by the farmer/teacher and the environment); sometimes, this beginning germinates into proneness; and sometimes it blooms into talent. If cut, while beautiful, it is short-lived as proneness; if left in the soil, it can make a lasting contribution.

Observation of a Rural District of Fourth Graders (1964)

Aim: To illustrate concept formation, based on prior experience and leading to a construct.

In the introduction to the lesson, the teacher probed what his students knew, asking what kind of farms were in the area, what the crops were, what types of plants and animals they cared for, and so forth. He elicited all this information apparently not only to prepare the children's mind-set but also to set them at ease. Then, the teacher held up four hens' eggs—two brown, two white—and asked, "If these were hatched what would come out of them?" The response, almost in chorus, "Chicks." One girl asked: "Are the eggs fertilized?" The teacher cracked one open; it was hard-boiled. Laughter. "Nothing but lunch will come out of this one."

Asked the teacher, "Suppose they were fertilized—then hatched. What would happen in the next weeks or so?" The boys and girls described how a chick was brought to full development into a hen or a rooster. They discussed such matters as diet, for example.

But the teacher noticed that one boy was silent, appearing inactive, and the teacher passed him an egg.

"Why not a duck, an ostrich?" the teacher queried. Softly, the boy said, "It doesn't have the DNA of these animals." With some encouragement, the boy was able to explain that DNA was in the cells of the growing chick. And, when asked—"What's DNA?"—he stood to answer, "deoxyribonucleic acid." He explained with some uneasiness that he learned about DNA first from a TV program; then, he went to an encyclopedia and to magazines; next, he consulted biology textbooks and had conversations with an older brother, then in high school. The construct developed before the end of the lesson: Living things inherit their traits from their parents.

Let me propose that the concept was evoked by questions probing prior experience and/or personal habits of inquiry, not by lecture. Further, the boy may have identified himself as science prone by exhibiting what Hudson called a "contrary imagination," that is, he saw a solution where others found a problem (1966). The boy was certainly idea-enactive and inquiry-oriented, but had the lesson been a lecture, his responses might not have come out. He might eventually exhibit science talent if given the opportunity to probe discrepant events in continuing years.

A later discussion with the four teachers observing the lesson revealed that he "liked" science and math but little else; in other subject areas such as spelling, he was an "underachiever"; he often seemed bored (although his contribution made it obvious that he read above grade level).

Such apparent contradictions are not in my observation unusual, and we discussed special provisions possible to accommodate such promising youngsters.

Observation of a Combined Class of Four- and Five-Year-Olds in a Laboratory School (1959)

Aim: To demonstrate a mode of seeding a concept that leads to further concept seeking and forming.

In preparation, the teacher had asked for plastic spoons, forks, cups, paper and plastic plates, paper napkins of several colors, sufficient for each group of students.

The teacher asked, "Suppose you were to group these things you have in front of you; put together the ones you think are alike."

No problem. The children worked quickly. Some put napkins together, others, spoons; others, plates; others, cups. Others grouped plastic things and paper separately. Several bunched everything together. Each group—in reasonable and conceptually based language—gave reasons for grouping the objects. Group 1 (girls and boys) "saw" the same shapes. Group 2 (girls and boys) "saw" napkins as different in texture; the other objects "together" were of different "hardness"—or "would last longer."

Group 3 (two girls) grouped everything together: One five-year-old explained that "all things are useful in eating a meal"; the other, almost five, "saw" all things as composed of matter—"like everything in the room." On being encouraged to elaborate, she said she "wasn't sure," but she thought "the entire earth was made of matter."

"Humans as well?" asked the teacher. Hesitating, she replied, "I think so." A discussion ensued—was "matter" a "thing" that "everything could be put under?" Could "matter" hold liquids or solids? "Matter" was *everything* was the general conclusion—whether liquid, solid, or gaseous.

Another boy had set a fork apart from everything else. When asked why, he responded, "Well, all the other things can hold water; the fork can't." The boy insisted that his idea was "workable." "By 'workable,' do you mean practical?" the teacher asked. "Yes. You use the idea all the time!" (Again, a "contrary imagination.")

Let me propose that all the young had properly put objects together in conceptual order. But those in group 2 were thinking in broader categories than those in group 1, and the two girls in group 3 were the widest conceptualizers. All these processes are indicators of idea-enactive, inquiry-oriented teaching and learning.

But the girl suggesting the concept of "matter" as pertinent was conceptualizing in science, thereby perhaps indicating science proneness and probing beyond the information known. In Bruner's terms (1979), she was exciting "effective surprise"—a trait characterizing a potential talent. Her teacher later said that the child often offered unexpected, insightful responses.

Let me propose that all the young had given evidence of the kinds of different concept seeking out of constructivist mental activity that might lead to concept forming in future lessons, thus perhaps tapping science proneness. The idiosyncratic thought and manner of the boy whose persistence (on isolating the discrepant fork) was indeed worth cultivating.

Observation of California Third Graders (1969-1970)

Aim: To use observation to uncover commonality and an initial approach to find hidden likenesses in human traits.

During attempts to develop a social science program for elementary schools, I visited a third grade class made up of mostly nine-year-olds from many ethnic groups, Hispanic young in the majority. The class, taught by an intern, was testing a unit in anthropology.

The teacher requested that her students close their eyes. Then, she asked, "Now think of your face—imagine how it looks in the mirror. Without opening your eyes, ask yourself this question: What parts of my face would I find on other faces in this class? I'll put my hand on your shoulder—when you raise your hand to respond."

The children laughed, giggled, and responded with excited comments. "Noses, ears, eyes, hair, lips, chins . . . ." Some hadn't raised their hands and protested jokingly when the teacher put her hand on their shoulders; nevertheless, they responded correctly. One chortled, "Glasses."

"Fine! Fine!" praised the teacher. "Now open your eyes. Choose a country you may know about. What do people there have on their faces?"

Apparently surprised by the simplicity of the question, the children named various countries and agreed that the features on their own faces would again be present. Except, as some suggested, different shapes to eyes, noses, heads.

Two boys and a girl shared a specific response—that is, all humans were one kind, with differences. The girl lucidly explained that humans everywhere were *Homo sapiens* and correctly defined the terms *genus* and *species*. Further, she recalled that anthropologists were trying to find out "in what part of the world *Homo sapiens* had originated." This child, in going beyond the information given, again established that knowledge and experience even in the very young may result in foresight and understanding, in knowing in advance. Hers was an expression of science proneness, demonstrating ability to make images as a form of critical thinking.[8]

Identifying Science Proneness: Six Interdependent-Independent Environments

Observation of a Combined Fourth and Fifth Grade Class (1989)
Aim: To study the concept of weight and lead to a concept of mass.

A boy brought up a problem one Friday: "I saw a boy balancing his father on a see-saw. The father was sitting near the hinge at the center; the boy at the end of the see-saw. How does this work?"

Several hands went up, but the class was ending, and the children and teacher agreed to take up the problem on Monday. By then, a girl had "invented" a model: A thin metal ruler on a pivot; four checkers on the ruler near the pivot; two at the end.

"If you know the length of the see-saw," she explained, "you can balance the weights. So W (weight of the body) x L (length of the board before the pivot) on one side of the fulcrum = W x L on the other side." She drew a sketch of the apparatus on the board. "I checked it up in a high school textbook, but I thought up the checkers as weights and made the fulcrum using the edge of a box." She then answered questions, particularly about her "formula."

Observation of Two Fourth Graders in the Midwest (1982)
Aim: To explore the uses of machines to save work

In a lesson on the uses of pulleys, two fourth-grade boys had "invented" a small model of a machine utilizing a pulley (similar to the ones used to hoist hay or bags of feed used on their parents' farms). Using a high school text found in the library as reference, they calculated the saving or "work."

Observation of a 10-Year-Old Girl (1983)
Aim: To demonstrate that the young through inquiry can practice independence training.

Stimulated, perhaps, by the idea-enactive behaviors evoked in the classroom, certain children take on individual investigations at home.

A fifth-grade girl had seen a TV show describing bean seeds' food storage. On her own, she planted 16 bean seeds in soil as follows: 4 with both cotyledons; 4 with one cotyledon; 4 with a half cotyledon (cut with scissors); 4 with no cotyledon.

With minimal advice on technique, she had devised a *hypothesis* (with less stored food, the seeds should not grow well), developed an *experimental technique,* and attempted to create a *controlled experiment.* She subjected fully leaved thriving plants to a similar environment favorable to photosynthesis. She repeated her experiment with similar results.

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[8]Some of these descriptions come from notes taken by teacher-observers.

She thought that the bean seeds would grow best with both cotyledons, do well with one, but be dwarfed or dead with half or none. She "assumed" that the young leaves would be able "to photosynthesize" but that the plants hadn't the "food energy" the cotyledons provided. In fact, the plants behaved as she predicted. She was unwilling to come to a "conclusion," however, when her experiment was finished, because she thought maybe her "technique" was faulty.

Observation of Sixth Graders in a Mid-Atlantic School (1982)
Aim: To make observations and prepare graphs

Sixth graders working on a project for their science fair were maintaining graphs of monthly gain in height and weight and comparing the growth of corn in a field on a graph that recorded time and growth (that is, the *x* and *y* ordinate and abscissa). They were able to draw the parallel that their plotting showed a possible similarity in growth between humans and plants.

Observation of Northeastern Children (1983)
Aim: To observe and record data

A team of youngsters joined to plot the length of daylight (time and hours of daylight from the onset of spring, summer, autumn, winter). Then, they formed a weather bureau.

Observation of Sixth Graders (1985)
Aim: To compare growth and kinds of plants in different ecologies

In a study of a field near their school, a group of sixth graders chose three carefully measured plots in three different environments—rocky, fertile in sun, and fertile in shade. Then, using a series of illustrated books in the library to attempt to identify the most common plants, they counted the types in each environment in relation to time of sprouting. The project fed their interest in environmental science.

Using Textbooks, Films, the Laboratory, and Other Supplementary Materials

In several elementary laboratory schools in university towns, textbooks and laboratory manuals from elementary to high school levels were kept for consultation and used mainly as references. Many on special subject matters—for example, astronomy, space projects, plant and animal identification, and oceanography, as well as junior and senior high textbooks in biology, chemistry, physics, geology, and ecology—were available in the laboratory. After third grade, a number of classes were offered a general textbook one grade or two above level for home use in preparation; the discussion, however, often deviated from the text.

When possible, films of laboratory experiments were shown first with the sound cut off. Then, after questions and observations, the sound was restored. Thus, the film could be made into an experience in observation. In many of the schools observed, the laboratory period was scheduled before the class lesson—thus increasing possibilities for individual and group inquiry.

A Certain Atmosphere

In many of the lessons observed, skills in reading, mathematics, and science combined with the experimental mode in classroom, laboratory, film, and field to provoke thought, experience, and foresight and to evoke discussion and interchange between teacher and students and student and student. Often, the teacher tried to get out of the way of the young experimenter, while offering guided-discovery tactics where necessary. Tobin, Briscoe, and Holman (1990, pp. 412-415) provide a discussion and demonstration of this mode of inquiring for the elementary school. They describe a situation where the teacher poses a question: "What part of the banana is edible?" Patient questioning by the teacher as well as laboratory apparatus (including bananas to be analyzed in measures with and without peels) led one of the young to an "intuitive leap." This, in turn, led others to build a solution—*E* (the edible part) = 2/3 *T* (the total weight). Robert had suggested a rough formulation—*E* = *T*, and Alice had built on it—*E* = 2/3 *T*. Guided discovery and the freedom of "experience in search of meaning" (Einstein's definition of science) could not find a better exemplar.

The cognitive conditions underlying the teacher's approach emerged from a program of research projecting modes of combining elementary mathematics and science teaching (Tobin & Jakubowski, 1989). Eventually, science teaching may well be based in both verbal and mathematical skills devised in curriculum; it may also be based in idea-enactive, inquiry-oriented instruction.

Class Discussion: The Interconnectedness of Experience

The elementary school lessons just described were concerned with teaching and learning, as children uncovered old knowledge and converted it into degrees of inquiry. But inquiry upon inquiry upon inquiry, unless turning into a search for meaning, can be sterile.

Through discussion, between teacher and students and among students, the class engage their thoughtfulness and understanding with others, enriching their further understanding in probes beyond the information originally given. Thus, deeper activity in the degrees of inquiry can lead into possible establishment of a principle. For students other than the discussants, the interchange evokes respect for the thought processes of others forged in links similar to those created in seminars. (See the colloquium in elementary school science described in Lansdown, Blackwood, & Brandwein, 1971.) Students come to understand that questions may have no present answers, indeed, may not have "correct" answers, but that each piece of information fits somehow into a whole—into an available concept or one to be sought in further mediating inquiry, in discussion, in the laboratory, in the library, in independent study, and so forth.

A distinctive purpose of classroom and laboratory discussion is, then, to probe the relevance of information gathered through inquiries following such different but interconnecting methodologies. Thus, the young are to seek relevance to conceptual schemes or concepts that yield further comprehension of the world and its work. Without an ordering in conceptual schemes, the science curriculum becomes a potpourri of topics without the unity and interconnectedness of prior knowledge. Clearly, the aim should be to inculcate a nexus of hands-on, brains-on, minds-on laboratory sequences leading to active discussion in class. Thus, the classroom is a place where a "society of ideas" (Simpson's felicitous phrase, 1957)—a society, if you will, of concepts—should thrive. In terms of developing science as an experience in search of meaning, concept seeking and forming become the legitimate, even the central objective of the teacher's art in the conduct of classroom discussion. Analyses and syntheses of generalizations central to the function of discussion in the classroom combined with independent study form "the concepts which again become the primer upon which further inquiry is based" (Schwab & Brandwein 1962, p. 112).

A science curriculum built around conceptual schemes is flexible and responsive to children's needs and interests. Such a program, far from being rigid, permits a consistent organizing principle, one that encourages incidental learning from the media or in special environments. Such a curriculum reflects both the ways of scientists and those of growing children as they progress into and retreat from the vastness of their universe. It permits the teacher to interpret the child's questions in a manner relevant to the kind of inquiry that results in individual activity. In 1962, at Harvard, Schwab in the Inglis Lecture examined the use of discussion in high school in joining inquiry with inquiry, while I in the Burton Lecture explored the significance of concept seeking and forming in inquiry in elementary school.

In each of the foregoing lessons, we note idiosyncratic attitudes by different learners to a problem at hand. Central to instructed learning is the creation of a new environment. If stimulating, the learning engendered engages old judgments on the road to thoughtfulness and understanding and forms different judgments significant in their newness to the majority of the young. Through this process, the young bring into focus certain concept seeking and sum up their experience and observation in concept forming.

In each lesson, we may observe the teacher's process in instructed learning. Teachers first create a new environment; in so doing, they turn objects into stimulating events. From the very beginning of the lesson, the young do science by making observations of these phenomena. Then, they do science by inventing idea-enactive experimental procedures, or in verbal or mathematical statements, or by reconstructing random objects into orderly categories. All these procedures are appropriate to inquiry-oriented teaching: Learning occurs when the students, through various forms of critical thinking, construct concepts that attempt to explain a turns of events. The teacher assists this working of mind on mind by adroit questioning during discussion that stimulates analyses and syntheses into further inquiry.

The form and turn of the teacher's questions are one of the prime arts in teaching: Questioning nourishes thought and is critical in turning information into knowledge and in encouraging learners to go beyond the information given and to form concepts that become the filing systems of the constructs of the mind. Knowledge transformed into concepts is the ground of a new recognition—knowing in advance—as the student fits a fragment or an event into conceptual frameworks built earlier through class discussion. A successful science lesson is signaled by at least two changes in behavior resulting in some mental transformation: First, the student goes beyond the information given; then s/he achieves the satisfaction of a new cognitive set by knowing in advance.

The lessons described above illustrate that children in elementary school can demonstrate science proneness through instructed learning. I was able to obtain information on student IQs in 102 of 272 classes observed; the range of the young demonstrating indexes of science proneness was from 115 to 156. Renzulli (1978) wrote,

> There are only a few educators who cling to a "straight IQ" or purely academic definition. "Multiple talent" and "multiple criteria" are almost the bywords of the present gifted student movement, and most educators would have little difficulty in accepting a definition that includes almost every area of human activity that manifests itself in a socially useful form. (p. 181).

In making the observations in this section and the next, I used the behavior scales teachers were expected to demonstrate to be licensed in New York City (1944-1954 when I was an assistant examiner). The scales corresponded in good measure to those developed to rate the behavioral characteristics of superior students (Renzulli & Hartman, 1971). Beginning in 1981 and ending with observations in 1989, I was able to use the Renzulli-Hartman Scale to check my observations.

As the young in elementary school demonstrate science proneness, they identify themselves as candidates for a beginning talent pool in science. Tests of mental ability may well be set aside at first. Instructed learning, the major relationship between teacher and students, furnishes paramount evidence of performance in the classroom. In a sense, the schools' labs and classrooms are our research laboratories as well.

Tannenbaum cautions that "In creating a pool of 'hopefuls' it is best to admit any child who stands a ghost of a chance of someday making it to the top of the world of ideas" (1989, p. 49). *A wide net is to be cast.*

Beginnings of a Talent Pool

Equal opportunity opened up through instructed learning may result in a seeming paradox: Namely, equality of opportunity may lead to situations where differences in expression of abilities appear. Such differentiated self-expressions through early study and work may become the first instruments through which peers, teachers, parents, or others contemplate differences among students in scope and in interests. These observations may lead to a common consent that a certain child may or may not be science prone.

Such programs offer the first steps toward attaining equal opportunity, that is, access to open enabling environments in which the young may immerse themselves in common literacies as well as take their routes to special excellence. Supporting appropriate ability testing is, then, acceptable following the evidence of *demonstrable* behaviors and/or products in the equal opportunities available in environments. Thus, the simultaneous amelioration of limiting environments and forwarding of enabling ones through curricular and instructional practices are both conceivable and practical.

Prototalent in precocious young often expresses itself in a burst of "effective surprise." Because science involves componential learned abilities for those who will demonstrate verbal, mathematical, and spatial abilities coordinated in problem solving, the early school years are the essential ground for recognizing science proneness. Construct I notes that many times early underexposure to and unsuccessful experiences with science and mathematics block expressions of science proneness. Noting this phenomenon and believing, in sddition, that U.S. science research is in trouble (1991), Nobelist Leon M. Lederman, who is past president of the American Association for the Advancement of Science and now at the University of Chicago, is engaged in trying to improve science instruction.

In a *New York Times* article "How to Save Science in the Classroom," Lederman (1992) writes of a 16-week intensive training program for 17,000 teachers in Chicago, 100 the first year, 1,000 the second, and 2,500 from then on. The programs work—the young, the teachers, and the administrators are highly enthusiastic. Lederman notes that the program is behind "schedule but the faculty is wiser and more determined than ever. To extend programs similar to ours to 25 other cities," he continues, "would require something less than $1 billion annually." While one important aim is the rejuvenation of the waning science-literate workforce, Lederman states that

> A debate used to rage over whether to invest in gifted students or the other 99 percent. It should be obvious that we need to do both: there is no real conflict for resources. We must take care of the super-bright.
>
> But we are also rightly concerned with the rest of the kids. Science and math could be tremendously attractive to inner-city children—if teachers let the children talk and work in groups rather than passively listen, if the teacher is the facilitator rather than the font of all knowledge, striving not for correct answers but for clues as to how the child thinks. (1992, p. A19)

Particular Characteristics of the Science Talent Pool

The description of the science pool as a "pipeline" comes generally from National Science Foundation and the Roundtable study (1987). The science talent pool is defined variously. Some count as members those who declare themselves interested in science during their freshman year in college. But others describe as the whole "pipeline" that 15-20 percent of students still showing interest in science by the end of their sophomore year.[9] The present study refers to the total number of high school students who at graduation remain science prone, plan to major in a science field, and have not irrevocably disqualified themselves by failing to take mathematics. This science talent pool begins in early schooling but is incomplete until graduation from high school, the years when motivation and abilities focus.

The Revolving Door Identification Model

This method, devised by Renzulli, Reis, and Smith, lays the base for a model—or a management plan—for putting into practice "a number of principles or guidelines by almost all persons working in the field of gifted and talented" (p. xii). Along with Renzulli's enrichment modes (1977), the revolving door identification model formulates comprehensive, detailed plans and practical devices and measures for evolving the potential of the gifted into "completed products and performances." According to Renzulli, Reis, and Smith,

> The Talent Pool is defined as those students from the general population who are above average in one or more areas of general ability and/or one or more specific performance areas. Entrance into the Talent Pool is ordinarily determined by one or a combination of the four families of information (i.e., Psychometric, Developmental, Sociometric, and Performance). (1981, p. 50)

Renzulli and his colleagues list a number of useful measurements to define those young who might thrive in this pool—test scores; completed products and performances; anecdotal records; observational reports; self-ratings and evaluations by teachers, peers, and parents; unstructured self-expressions, and classroom performance (p. 32, Fig. 9).

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[9]There has been considerable controversy in the early 1990s both about the size and the future significance of this science-prone sophomore group. For years, the National Science Foundation figures placed it at about 20 percent of the class nationwide; in 1991 its *Indicators* cited figures from the Longitudinal Study of American Youth as about 22 percent (dropping to about 16 percent by senior year) (p. 24); 1993 *Indicators*, basing themselves on the *High School and Beyond* studies put it lower, at 15.5 and 10 percent, respectively (p. 13).

My observations of the revolving door method at work show it to be especially useful in identifying children for the talent pool in science when a regular teacher spots a science prone student. The talent pool group of youngsters is estimated to be 20 percent of schoolchildren (for example, 50 of a group of 250).

The soundness and practicality of the revolving door identification model approach is rightly widely accepted. Of particular significance here is its utility, along with idea-enactive, inquiry-oriented teaching and learning, in advancing a program of self-identification and self-selection through performance for the beginnings of a science talent pool.

Self-Identification: Raw Indexes of Science Proneness

The following are some of the inquiry-oriented, idea-enactive behaviors noted in my observations of the young in their lessons in science in elementary school. (See also Walters & Gardner, 1986.) Each notation represents a cluster of 3 or more observations made in 272 different elementary (grades 1-6) and middle school classrooms between 1938 and 1986. Such behaviors offer a teacher clues to the existence of nascent interest, even before it focuses in science proneness or definitive talent.

In no particular sequence, a future in science may evolve in a child who

- participates readily in discussion after a science demonstration and in so doing defines his/her terms
- inaugurates an experimental (discovery) procedure in the mode of a hypothesis—for example, begins with "What if . . ."
- speculates by asking questions—(whether correctly or as guesses)
- invents equipment to solve a problem and/or shows ingenuity in devising experimental designs
- goes beyond the information known to the class, as evidence of individual initiative, interest, or reading
- prepares for the next day's work by self-initiated reading or investigation
- thinks conceptually or comes easily to an abstraction
- becomes absorbed in a subset of science—for example, life, matter, or energy
- acts spontaneously in uses of science vocabulary or uses imagery to call up pictures of scientific apparatus to solve a problem
- brings to class a project of her/his own, or is eager to enter a science fair, and/or is a member of a science club
- shows strength in areas congruent with science—for example, literacy, numeracy, imagery and, in concentrating in science, may neglect other content areas (for mature use of all capacities, this imbalance should be corrected early)
- explains and rectifies misunderstanding in other children and does so patiently
- renders reports coherently, dealing in his/her way with substance, structure, and style
- expresses concepts in mathematical terms and takes to mathematics readily
- is a wide-conceptualizer—for example, relates the sun's light to a plant's growth, explains the orbit of planets in relation to gravitational pull, connects the needs of organisms to their environment, tends to explain objects and events in reasonable interconnections

- seems ready early on for individual work and therefore for independent study at home or library
- shows interest in the relation of science to society—for example, in the problems of pollution or pesticides—and demonstrates this bent in his or her reference in class to conserving life, matter, and/or energy
- draws on TV programs in science and reports on experiments
- brings to class clippings about recent discoveries
- adds to understanding and foresight, but does not dominate in a colloquium
- has a general library at home, some of whose collection leans to science, and sometimes brings these books to class
- makes known to other teachers his/her interest in science
- shows obvious ability in intellection and in science but is sometimes withdrawn; nevertheless, responds to encouragement and individual attention
- participates in distinctly science-oriented hobbies—for example, observes meteor showers or collects fossils
- is interested (indeed, at times, almost devoted) to computers, mathematical puzzles programmed in hand-held computers (a pattern emerging in the late 1970s)
- shows readiness in the fourth or fifth grade for an enriched or accelerated program in mathematics and science
- experiments at home with science kits and computers
- shows interest in photography and sometimes accompanies class reports with photographs
- reports on collections and brings projects to class to share with others—for example,
    - collects rocks and crystals
    - identifies plants through leaves and drawings
    - describes and demonstrates a home weather bureau
    - organizes clubs such as junior astronauts
    - builds small motors (sometimes from kits)
- uses microscopes avidly and is an accurate illustrator of microscopic organisms.

This list of idea-enactive, inquiry-oriented self-identification behaviors is similar to those on Renzulli and Smith's "Early Childhood Check List" and other lists and questionnaires (Renzulli, Reis, & Smith, 1981). All these observations of raw or unmediated development may also include certain characteristics of young on the road to focused commitment.

Tennant (1980) uses grouped observations like these to identify specific concept *seeking* (questioning of events), *forming* (from inquiry or investigation in project or experiment), and *transmission* (reporting of the inquiry). The insights gained from observations of such idea-enactive, inquiry-oriented behavior, regularly repeated under the conditions of instructed learning, can help to identify students as science prone. Self-identification is also valuable. Both kinds of data showing science proneness can form the beginnings of a science talent pool. They can serve as a kind of field research prelude to particular practice—for example, participation in further self-selected projects or in strategies such as the revolving door model or idea-enactive, inquiry-oriented teaching.

In Sum: Instructed Learning as a First Identifier for the Science Talent Pool

If idea-enactive, inquiry-oriented teaching as a strategy of instructive learning becomes general practice, *then,* in the revolving-door identification model, it may become a mode of early self-identification of the young in their response to its multiple stimuli. Later, early instruction may be modified into more sophisticated experimental procedure and well-ordered empiricism in the classroom and laboratory. In the fourth through seventh grades, this combination of processes requires a resource room fully equipped as a laboratory; ideally, it would also require computers. Under these circumstances, the young then begin to do science not as learners mainly of described procedures (in the rhetoric of conclusion) but in the activity and guise of the scientist.

Idea-enactive, inquiry-oriented instruction, as described in the lessons above, becomes a first procedure in observing the young in early achievement in science. The complex of such behavior plus ability and achievement testing can then become part of a cumulative record, which can be compared and contrasted with *field-specific* demonstration of ability in science and mathematics. Formal testing per se is *not* to be the gate to entry into differentiated programs in science and mathematics. *If* final judgment on selection for differentiated instruction in science and math is withheld until late middle school, *after* the young have had the chance to identify themselves for it, *and* their choice is followed by consistent science-specific *works, then* we have a better picture of in-context potential signaled through performance.

The sum total of the modes of entry into the science talent pool should be generous, implying the casting of a wide net, so that equity and competence and/or performance in science are served. Children demonstrating any of those behaviors would be eligible for the enriched "revolving" experiences in the resource room with a teacher equipped to advance their experiential and experimental inclinations.

In accepting science as experience in search of meaning and in helping children to discover for themselves, teachers can induce science prone young to become lifelong learners. They will come to express their proneness not only through independent study, but also through performances, apart from explicit texts, manuals, and laboratories, that demonstrate the critical thinking and thoughtfulness of the scientist. When this happens, especially early on, the young seem to identify their interests in instructed learning as a design for study embracing the full spectrum of subsets in science. By the fifth and sixth grades, the raw indexes of competence and performance can already appear in focused inclination. We begin to find those who lean to biology, to physics, to chemistry, to earth science, to environmental science, and to field study. There begins—already—to emerge the first evidence of interests that may mature into particular kinds of adult professionals—

- the technician (who creates, modifies, and fixes apparatus)
- the computer specialist (at whose roles we can only begin to guess)
- the experimenter (who demonstrates laboratory skills)
- the theoretician (who offers concepts and, sometimes, mathematical constructs)
- the skeptic (who questions)
- the scholar (who reports)
- the maker of intuitive leaps (who surprises with accurate hypotheses)

In any event, in late middle school, the science prone—and the sports prone, the word prone, the arts prone, and the dance prone—begin to sort themselves out.

Running between the lines of descriptions of programs and selection procedures designed to identify abilities is the assumption that, in such environments, the *curriculum* favors their cultivation.[10] A given curriculum—what content is to be taught—and instructed learning—how it is to be taught—are distinguishable. Thus, teachers covering the same curriculum using varying modes of instructed teaching evoke in the young different behaviors. Some science prone children, consequently, may not have the chance to identify themselves. Effective science teaching requires an idea-enactive, inquiry-oriented approach.

For this reason, this study explicitly defines a mode of instructed learning: It offers a number of lessons coming out of field research to illustrate substance, structure, and style in teaching the young to gain competence in learning and performance. After children have experienced instructed learning in elementary school, ability testing can be useful, with other acceptable measures, in correlating activity. Such tests are *not* to be used as predictors or criteria for access. Criterion sampling through the in-context testing of performance in the resource room should carry serious weight.

If a child selects him or herself, based on prior excellence demonstrated in idea-enactive, inquiry-oriented instructed learning, particularly in the laboratory and/or with computers, equitable opportunities will allow further performance and demonstration of potential. A generous period should then be available for the young, with guidance from staff, parents, or mentors to choose future programs.

A strong conclusion: In any research on evaluation of competence and/or performance in learning, the mode of instructed learning used should be specified. The mode may well be the critical identifier as to whether abilities significant as indexes of science proneness or expressions of science talent emerge early.

In the Interim: An Approximation of the State of Affairs in the Early 1990s

None of the National Educational Goals Panel reports for 1991, 1992, 1993, and 1994 show much progress toward the "math/science goal" (originally goal four; now, goal five) that American students will be "first in the world" in those subjects by the year 2000. The summaries show that the last item in the syndrome of 10 (namely that little science is taught in the elementary schools) continues to hold. In 1991, the Panel noted that, in the late 1980s, 70 percent of third grade teachers spent two or fewer hours in science per week, while 6 percent did not teach it at all. The average time devoted to science in grades four to six was little more than one half-hour per day. A third of fourth, fifth, and sixth graders had no science equipment in their classrooms, and "less than 50 percent of science teachers in the upper elementary and high school grades reported using hands-on activities in class in their most recent lesson" (p. 55).

In 1992, the picture remained bleak, with the Panel citing the large numbers of precollege teachers at all levels who both *feel* and—in terms of credentials, at least—*are* unqualified to teach science and math (p. 36). Indicators in the 1993 report were slightly more encouraging. In spite of the fact that teachers said that fourth and eighth graders "were not receiving the kind of instruction recommended by mathematics education experts," eighth graders' use of calculators in class increased somewhat. In addition, over the past seven years, the number of advanced placement examinations taken in the sciences

[10] Remember Macdonald's essential distinction between *curriculum* and *instruction* as relevant but distinct fields (1965).

and mathematics has increased significantly—by 64 percent in biology, 83 percent in chemistry, 129 percent in physics, 91 percent in calculus (p. 88). The State Goals Report in 1991 notes that the percentages of students *taking* classes in nonbiological sciences remains fairly low: While 80-95 percent take biology, only 40-60 percent attempt chemistry; and 10-20 percent try physics.

In the summary data "measuring progress toward the goals" recorded state by state and territories, *all* in 1991 reported "no comparable state data available"; only Colorado modified this statement in 1992. By 1993 and 1994, all states except Kansas, Alaska, and two of the territories reported *some* data; but they were frequently incomplete and difficult to interpret.

From the data supplied by the states in the *Goals Panels Reports,* along with that provided by the National Center for Education Statistics in Table 1 below, it appears that math preparation in high school is on the rise. While this is good news, it needs to get better.

These data suggest that American high schools are central to augmenting the science talent pool. Rakow (1989) notes that "we are at the beginning of the preparation of instructional programs that build on the experience of the gifted young in the middle school: A critical period in their identification, instruction, and guidance" (p. 146). He then gives examples of such programs.

Table 1

Percentages of Public and Private High School Graduates Who Took Advanced Mathematics

	1982	1990
Algebra I	65.1	77
Algebra II	35.1	49.2
Calculus	4.7	6.6
Advanced Placement Calculus	1.5	4.2

Data from sample surveys compiled by the National Center for Education Statistics (Department of Education) on the basis of transcripts of high school graduates. (1993, p. A-144).

Objectives to Be Met

A number of groups are at work to attempt to make American students "first in the world" in math and science by 2000. As former National Science Foundation Head Massey[11] notes, "Whatever that means and whatever the significance of international assessments and their sample populations, America's children are not at that point now" (1991). But the United States *attempts* to educate all its young, not just selected elites.

The 1993 National Science Board *Science and Engineering Indicators* notes that this was not always the case:

> In 1945, the Harvard Committee on the Objectives of a General Education in a Free Society—a committee made up of some of the most distinguished scientists and educators in the country—echoed the conventional wisdom of the time when it recommended excluding half or more of the young people in the United States from advanced coursework in science and mathematics. The committee argued that "little more than half the pupils enrolled in the ninth grade can derive genuine profit from substantial instruction in algebra . . . (Harvard Committee, 1966).
>
> In the ensuing half-century, attitudes (if not practice) have changed with regard to science and mathematics education at the precollege level.
>
> Today reformers call for the popularization of high-level mathematics and science coursework; this reform movement is fueled by concerns over our Nation's economic competitiveness, society's ability to cope with advanced technology, and the pipeline that produces this country's scientists and engineers. The calls for more instruction and higher achievement in mathematics and science for all students are also part of a larger trend of expansion and inclusion in U.S. education. Since World War II, access to public education has dramatically expanded, and the curriculum has diversified along with the student population. (p. 3)

The National Education Goals Panel (1991, 1992, 1993, 1994) defines supporting objectives to the "math and science" goal:

- Math and science education will be strengthened throughout the system, especially in the early grades.
- The number of teachers with a substantive background in science will increase by 50 percent.
- The number of U.S. undergraduate and graduate students, especially women and minorities, who complete degrees in mathematics, science, and engineering will increase significantly.

A massive effort, a gargantuan task, seems in the making. National, federal, state, and local, nonprofit and proprietary, industrial and postsecondary groups are joining America's schools to advance the skills of teachers and the quality of instruction for K-12 science and mathematics. The pool of well-schooled and educated young may then increase and so too the science prone.

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[11]Massey is currently Provost and Senior Vice President of Academic Affairs at the University of California Office of the President.

Construct IV: Enabling Achievement—A Curricular Approach Designed for Self-Identification in Conjunction With Instructional Practice

Construct III set forth a theory and specific examples of instruction, which provide an exemplar of instructed learning emphasizing powerful idea-enactive, inquiry-oriented teaching and learning. Construct IV will focus on young who show particular promise in science rather on those with more general gifts.

Siegler and Kotovsky (1986) posit that "the fit between the individual and the field is important for both intellectual and motivational reasons. A superior fit allows the individual to learn quickly and deeply the material in the fields" (p. 419). An essential element in this "fit," which in turn is necessary to the creation of a significant science talent pool, is the function of curriculum and its congruent instructed learning as valid identifiers of science talent. This study concludes that the science talent pool is incomplete until the young at promise of such talent are assessed through several exemplars. The young at promise for science give evidence of two qualities: They early show exceeding competence in acquiring knowledge in a specific field, and they early perform excellently demonstrating their powers of originative inquiry in a work. Because gifted young can begin to demonstrate heightened capacities in earliest schooling, they should be given opportunity to fulfill them in pursuit of excellence. In the particular terms of this study, they need a chance to demonstrate their science proneness.

Enabling Augmenting Exemplars for the Science Talent Pool

Provisions for acceleration and enrichment are numerous—as are critiques, both positive and negative (Gallagher, 1984). In their useful compilation of studies attending to the *Academic Acceleration of Gifted Children,* Southern and Jones address and analyze 15 modes of acceleration under these headings: Earlier entrance to primary grades, grade skipping, continuous progress, self-paced instruction, subject-matter acceleration, combined classes, curriculum compacting, telescoping curriculum, mentorships, extracurricular programs, concurrent enrollment, advanced placement, credit by examination, correspondence courses, and early entrance into junior high, high school, or college (1991, p. 2).

Other theoreticians proposing instructional strategies and tactics that offer acceleration and enrichment fitting these criteria include Davis and Rimm (1988), Kitano and Kirby (1986), and Passow, Goldberg, and Tannenbaum (1967). These strategies, complementing each other as definitive practices of administrative and instructional procedures, are selected exemplars of augmenting programs to fit a variety of talented young in science for postindustrial participation in a global arena.

The enterprise of the family-school-community, cultural, and college-university ecosystems sometimes stands in the way of tolerable choices of curriculum. These ecosystems have not yet developed the procedures that allocate programs, financial resources, and expertise necessary to collaborate in resolving problems intruding on this commitment to developing the desired abilities of *all* young in *all* their variety in gifts, talents, and destinations.

A Curricular Structure Facilitating Augmenting Environments

Conant's (1947) definition of the field of science as a "series of conceptual schemes" correlated strongly with the thinking of the complementary science study groups that gathered in the curriculum reform movement of the late 1950s and early 1960s. Each study group organized its structure around major conceptual schemes, with an ascending and supporting ladder of concepts. For example, the BSCS green version textbook focused on one major conceptual scheme among several, in this case—"The World of Life: The Biosphere"—and subtended, "The Web of Life," "Communities and Ecosystems," "Individuals and Populations." The CHEMS study chose as a major conceptual scheme—"The Particulate Nature of Matter"—and included as subsets, "Atomic Structure," "The Periodic Table," "Molecules," "Chemical Bonds," and so forth. Similarly, the PSSC structured physics, and other committees similarly organized other scientific fields, under overarching concepts and subsets. (See Appendix A.)

When various publishers prepared their texts independently, they frequently adopted similar curricular structures and conceptual schemes (however phrased or modified). But, most significantly, the elementary and middle schools adapted general conceptual structures in developing their curriculums. Students generally used a series of three books for grades seven through nine and six or seven books kindergarten through sixth. An ascending structure in difficulty of concepts and subconcepts accompanied advancing grade levels.

Thus, compacting and fast pacing were not difficult to accomplish: Science prone young could easily leap a concept or subconcept (always utilized and therefore reviewed in the next grade). For example, classes for six-year-olds might begin with a first grade text and hands-on laboratories and enrich and compact the curriculum for those students showing interest with second grade materials (fast pacing); in the second grade, these children were therefore enabled to study materials usually designed for third graders, and so on.

The curricular structures in programs planned prior to those employing conceptual models were typically structured from simple to more complex topics. In practice, such curriculums could not demonstrate the clear nexus of the conceptual structure, which facilitated cognitive interconnectedness.

In terms of the expression of a field-specific science proneness, fast pacing is facilitated by a conceptual structure in the elementary and middle grades preparatory to a similar curricular structure in the high school (see Appendix B). Further, as Abelman suggests, TV can give

> gifted children an opportunity to observe and familiarize themselves with advanced or abstract concepts and relationships that are normally learned at a later age through other media (i.e., books). Similarly, viewing allows them to practice their perceptual abilities, developing linguistic and critical-thinking skills, and puts their knowledge of the real world to the test. (1992, p. 4)

Completing the Science Talent Pool

The beginnings of the talent pool call for idea-enactive, inquiry-oriented instruction as a mode for stimulating elementary and middle school students' early interest and activity in science. This instructional mode is posited as a valid identifier of science proneness both by the children themselves and by their teachers. Together with measures of ability testing, such early teaching and learning continued throughout elementary and middle school should determine what verbal and mathematical measures would help to uncover science proneness. In any event, in this schema of intervention before high school (including the science annex of the revolving door identification model), the young select themselves—or are carefully guided by counselors and parents—for an augmented science-mathematics curriculum. This may occur either through instructed learning in a unitary science course that draws on math skills or through the two fields studied in tandem.

At present, however, high school is mainly where further expression of science proneness and/or talent is empowered. Three major exemplars in the design of augmenting high school environments designed for those with promise in science are identifiable: a pervasive exemplar, another fast-paced in content, a third based in originative inquiry and enriched in acquisition of knowledge. Each exemplar is at times sustained in resources of the cultural ecosystem.

The National Research Council's study *Fulfilling the Promise* (1990) points to the young's use of the laboratory in originative inquiry as a mode of self-identification of science talent:

> A substantial consensus has developed among investigators of "giftedness" that an environment that encourages inquiry provides the best opportunities for all students to learn (Brandwein & Passow, 1988). The role of the laboratory . . . is therefore central to successful instruction; if opportunities are made available to all, students with the appropriate abilities and interests will identify themselves with scientific activities with an appropriate degree of challenge (Brandwein & Passow, 1988). In some schools, it might be possible to provide opportunities for involvement in the scientific process outside the classroom and outside the curriculum. That involvement can be especially important in sustaining the enthusiasm of the students most likely to choose careers in science. (p. 73)

In many elementary and most middle schools, some or all of the augmenting programs described by Southern and Jones are in general practice (1991). Their increase is noted in the impetus of current reform in elementary and middle schools. In spite of the efforts of current reformers, most high school science programs still follow the traditional, pervasive mode in curriculum and modes of instruction not only in the United States but also in most of the Western world.

The Traditional, Pervasive Exemplar

The pervasive exemplar in high school includes the curricular and instructional matrix in public, independent, and special schools in the family-school-community ecosystem. With preschool and other presecondary institutions, the high school is the gathered source of young who will complete the science talent pool. The syndrome of 10 has, unfortunately, flourished in secondary schools worldwide but is now being neutralized. The thrusts of reform are encompassed in essential modes of instruction under the rubric of conceptual curricular frameworks and delivered through idea-enactive, inquiry-oriented instruction and revolving door identification model methods. The changes required will affect succeeding precollege enrollments between 1993 and 2002 of 48,410,000 kindergartners to 52,996,000 seniors. (These projections, from the National Center for Education Statistics, combine both public and private schools and include most preschool enrollment [1991b].) It will be up to today's fourth and fifth graders to reach the goals of the year 2000.

The pervasive exemplar in most American high schools, excluding those concerned primarily with vocational education, is the college preparatory program. Kuhn (1970) summarizes a prevailing practice in science education in high school and college:

> Why, after all, should the student of physics, for example, read the works of Newton, Faraday, Einstein, or Schrödinger, when everything he needs to know about these works is recapitulated in a far briefer, more precise, and more systematic form in a number of up-to-date textbooks?
>
> Without wishing to defend the excessive lengths to which this type of education has occasionally been carried, one cannot help but notice that in general it has been immensely effective. Of course, it is a narrow and rigid education, probably more so than any other except perhaps in orthodox theology. But for normal scientific work, for puzzle solving within the tradition that the textbooks define, the scientist is almost perfectly equipped. (pp. 165-166)

Siegel (1988), who disagrees with this view, wrote, "As I interpret Kuhn, his view forces upon us a conception of science education which is antithetical to a science education which takes seriously the ideal of critical thinking" (p. 168). The exemplar Kuhn described, practiced in different intensities in various high schools, is based in a lecture/prepared laboratory mode with foretold conclusions generally accompanied by limited discussion. The lecture-textbook mode, however, remains basic to instruction.

This exemplar held, according to most of my observations, from the 1930s to the 1980s. As the years went on, most of the 600 schools I visited still adhered to the laid-out laboratory, but an increasing number used computerized programs to increase the sophistication of the scientific puzzles. Some 130 of the 600 schools, however, and 8 of the universities (at the undergraduate level) carried on practices—to greater or lesser extent—that were clearly exemplars of originative inquiry. The majority of these 130 schools encouraged individual and group experimentation as well as participation in the Westinghouse Science Talent Search. The eight universities gave selected students opportunities to assist in research before graduation. In spite of some experiments in recent years, there is every reason to believe that the lecture-textbook-guided discovery approach is typical of the coverage of science content in most public and independent high schools in the United States.

The predominance of the exemplar may underlie why this approach, prevalent in secondary and postsecondary institutions, has filtered into the elementary and middle schools. There are other modes in substance, structure, and style of instruction in university and college instruction, but the model Kuhn describes is general in virtually all college-preparatory schools. (See also Sirotnik, 1983, and Goodlad, 1987, p. 11.)

It is still the road to the credential to enter college and university as well as to graduation from the university. In turn, this credential opens doors to further participation of the novice scientist in the originative inquiry that adds to science and technology. Humphreys (1985) reports "differences among chemistry, physics, geology, and engineering [as] measures of attainment are obviously produced during postsecondary education" (p. 341).

Deviations within this pervasive exemplar exist. Descriptions of some of these catalysts follow, as well as models of fast-paced and originative inquiry.

Catalysts: Augmenting Pull-Out and Out-of-School Programs as Part of the Pervasive Exemplar

Passow (1989b) reviews a number of innovative science programs of several types enriching the pervasive exemplar. Such opportunities are available to "thousands of precollege high-ability students" chosen for participation nationwide for a "tremendous variety of science and mathematics programs on college and university campuses" (p. 246). Some combination of evidence of strong interest is usually required for admission: For example, a high grade point average, good performance on standardized tests (including the Scholastic Aptitude Test and/or the American College Test), and recommendations from teachers may be required. Passow points out that "Some programs are specifically aimed at recruiting minority students and are restricted to qualified students who come from particular racial or ethnic groups" (p. 246) and cites Lieberman (1985) who found three major approaches for collaborative efforts between schools and colleges/universities:

1. The oldest pattern and the most popular strategy is early admission of academically able students to college.
2. A second pattern sets up cooperative programs between colleges and universities to improve teachers' professional growth.
3. The third pattern involves "institutional restructuring" aimed to change articulation patterns through new high school-to-college structures; to loosen the rigidity of the typical 12 grades of sequential study before college; and, as well, to unify the articulation of schooling with further education.

Here too, note the mutualism between the school and community and the catalysts in the wider cultural ecosystem.

Passow (1989b) describes a number of illustrative programs that may serve as models. They include the Minority High School Student Research Apprentice Programs at the Alabama State University and the University of Alabama, the Columbia University Science Honors Program, the Long Island Center for Gifted Youth, the University for Youth (Denver), and the College Studies for the Gifted at Fort Hays State University (Kansas) for intellectually, dramatically, artistically, and musically gifted precollege students aged 10-18. The criteria for admission vary; they include combinations of IQ, scholastic aptitude, achievement scores, and—where chosen and appropriate—performance screening.

Laboratory, museum, and research centers, too numerous to mention here also try to interest precollege students and to provide opportunities for teachers to improve their knowledge and teaching skills. Scholarships are available. Passow points out that

> These cooperative efforts are highly significant in the identification and development of scientific potential. They are part of the overall process in talent development, supplementing—not replacing—the learning opportunities provided within the school itself. Whether students are able to profit from additional personnel, materials, programs, and resources depends, to a great extent, on the kinds and quality of experiences provided by their schools. (p. 253)

Three Interventions Through Augmenting Curriculum and Instruction

Exemplar: Fast-Paced Curriculum and Instruction Within a Discipline

Lynch (1990, 1992) discusses a special fast-paced summer program in science for the "academically [sic] talented" with provisions for instruction in a residential setting.[12] In this program, sponsored by the Johns Hopkins Center for the Advancement of Academically Talented Youth (Baltimore), high school students took one course in biology, or chemistry, or physics on a college campus. Basic to the rationale of the program, from the standpoint of developmental and cognitive psychology, are studies by Stanley and Stanley (1986) and Lynch (1990), who quotes Hopkins' Program Director Durden's summary of its "basic premises." Students should

1. have opportunity to fulfill intellectual aspirations regardless of age when such abilities are identified;
2. be permitted to advance in accordance with individual rates and performance in learning;
3. have appropriate curricular plans "to respect a natural sequence of learning";
4. not be inhibited by inflexible, "artificially framed" curricula and unimaginative management of student time, [which] restrict their motivation and "thirst for learning"; and
5. . . . will best advance and mature through full and creative use of available resources, in and out of school. (p. 147)

These basic premises, applicable to all augmenting programs, may differ according to the intellectual aspirations of students. These aims may be fulfilled in fast-paced courses or in rigorous study combined with originative inquiry.

Lynch (1992) describes such a program designed for a three-week course of study to teach introductory high school biology, chemistry, or physics to 12- to 16-year-olds. The total amount of instructional time for each course was 82.5 hours compared to the 135 to 165 hours or more provided in most high schools. Students did 37.5 hours of lab work over the three-week period, double the minimum requirement of the New York State Department of Education, a standard chosen because of its "specific requirements and because its educational system is highly regarded." Lynch asserts that "the results of this research demonstrate that academically talented youngsters can master the secondary [school] sciences approximately two years before they are normally offered in American schools, and in about half the time typically spent in school" (p. 147).

The minimum Scholastic Aptitude Test scores for 12-year-olds seeking admission to the Hopkins' Center courses was equal to the mean scores of college-bound high school seniors—500 or more on the math section and a combined score verbal and math score of 930 or more.[13] Lynch (1990) estimates that, based upon these criteria, 1 in 200 American 12-year-olds would qualify for the Hopkins' science classes. According to Lynch, children with these scores appear to have already attained the level of cognitive operations required for high school science (Keating, 1976). The Hopkins' Center courses were intended to put the student on the road to further achievement in the chosen subject—for

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[12]Commuter programs are also offered.

[13]Although merely being invited to take the Scholastic Aptitude Test in middle school is looked on by many as an honor, some children have reported frustration at facing material on the test—such as in calculus—that they have never seen before. Even if the test is not required and no penalties are attached, the search of groups working to reform math and science testing to design instruments that teach as well as assess (page 161) seems a promising direction.

example, to take College Board Advanced Placement courses, university-level science courses, or other advanced science study. Significant pretesting and posttesting data are offered.

In the biology course, students met with their instructor (a high school advanced-placement teacher or a college professor) for three hours of lecture and discussion, followed after lunch by a two-and-a-half hour laboratory (taught by a college senior or a graduate student), and capped by a mandatory two hours' of evening study for homework, laboratory reports, and readings (Lynch, 1992, p. 148).

Lynch's valuable insights into the rationale for augmenting fast-paced programs in science include her summary of the program's contribution to the emerging picture of science talent and its antecedents. She explores the relationship between mathematical and verbal ability and achievement in science. Educators may find this information useful in considering prerequisites for honors science classes, since the evidence is clear that IQ patterns alone do not contain sufficient information for forming special academic groupings. Lynch writes,

> . . . Students can learn high school sciences successfully at a far earlier age than is typically allowed in our schools. Although the current concern for improving science education for all children seems well justified, some additional attention to improving opportunities for the gifted and talented to advance in science at a faster pace would also seem warranted. (1992, p. 153)

Stanley (1987) described another residential accelerated program, that of the Texas Academy of Mathematics and Science. For admission, 10th graders must score a minimum of 550 on the Scholastic Aptitude Test mathematics section and achieve a composite of at least 1,000 on the math and verbal sections. This composite, Stanley noted, is higher than that earned by 61 percent of college-bound male high school seniors. The average composite score for the 190 students entering the Texas program in 1990 was 1,205.

These selected Texas sophomores undertake two years of college work taught by university faculty; they study two semesters each of biology, chemistry, physics, and calculus, plus 24 semester hours of well-integrated English, social sciences, and humanities. Those who maintain good grades in their college courses can register as juniors in the University of North Texas for a baccalaureate or transfer to a state university (often with a scholarship) for their last two years of college. If these students also want a high school diploma, they complete the last two years of high school and the first two of college simultaneously, in a fast-paced program.

The state subsidizes each student for two years with sums equal to those awarded per pupil to all Texas communities for high school instruction, though students may have to pay a nominal fee to the University as well. There are also scholarships available. Serving as catalysts from the culture outside the family-school-community ecosystem, these entities act in mutualism to fulfill their purpose of establishing an augmenting environment.

Clarkson University (Potsdam, New York) offers a similar one-year program for seniors; there are others.

Exemplar: Originative Inquiry Within a Flexible but Rigorous Course of Study

The basic premises, developed in the researches of the psychologists Edgerton and Britt and published in 1943 and 1944, were, I believe, modified in practice by the

Washington, DC-based Science Service. In consultation with leading scientists sitting on the student assessment panels, Science Service inaugurated its Westinghouse Science Talent Search in 1941.

Thanks to Westinghouse's resources and the dedication of many distinguished scientists and educators, Science Service furnished the catalyzing exemplar. Following that model, by 1994, were 35 state science talent searches, affiliated with Science Service and coordinated by various state departments of education or collaborating universities. Innovative programs, fitted to the needs of prototalented science students, were inaugurated in selective science high schools and heterogeneous schools with exemplary science curriculum and instruction. In 1994, 43 states and Puerto Rico, and the District of Columbia were represented in the Search. In the 52-year history of the Search, New York, which is usually near the top of the nation in average expenditures per pupil (see Figure 1), has been far and away the leader in winners and runners-up. Between 1942 and 1994, New York schools have produced 690 finalists and 4,618 semifinalists (nearly a third of the totals awarded in both cases). In comparison, the next highest state, California (which spent slightly below the national average per pupil in 1989-1990) has had 146 winners and 886 runners-up.

The rationale underlying this exemplar follows: Students are to plan and complete an independent, originative inquiry predicated on the philosophical and epistemic ground essential to the credential of the novice scientist and characteristic of the mode of the working scientist. The premises of this exemplar stand on an empirical base of a longitudinal study of 50 years (Sherburne, 1987; Phares, 1990). In contrast, all of Lynch's and Stanley's studies base their models on young *at promise;* the competence of the students admitted to their programs has been demonstrated by test scores.

A talent in originative inquiry, demonstrated empirically in high school *performance* in the Science Search, seems to be a predictor of an advanced degree leading to—if individual choice warrants—a career in scientific research or in a related academic field (see Table 2). In the near future, data should be available on the success of other programs such as those at Hopkins or the Texas Academy in predicting their graduates' records as researchers. In any event, the young in both programs have demonstrated specially desired abilities: At the time of their rites of passage from high school to the university, they are valuable members of the talent pool and candidates for eventual careers in science. The caliber of their originative inquiry establishes a criterion sample buttressing prediction of science talent. Thus, because successful originative inquiry resulting in a work is an early expression of science talent, it can and should be made part of the high school science curriculum.

Congruent to both the pervasive and the originative exemplars is the inadequacy of IQ patterns alone to predict science talent, a position similar to that taken by the aggregate of authors in *Conceptions of Giftedness* (Sternberg & Davidson, 1986) against IQ as a sole predictor of giftedness.

Exemplar: Science Talent-Oriented Schools

A number of select science high schools similar in prerequisites and objectives to the Bronx High School of Science and Stuyvesant High School in New York City have developed in recent years. The latter traces its achievements to 1904 as a "technical" high school—and thus early on trained excellent artisans—and later developed programs for the science talented. It is now considered equivalent in quality to the Bronx High School of Science. The entry populations to both these schools and most similar others are academically talented students with prior records that place them high in some or all of these categories:

- their middle school classes (usually in the upper 10th percentile)
- grade point average
- IQ
- verbal and mathematical ability as measured on tests such as the College Entrance Examination Board verbal and mathematical segments and the Preliminary Scholastic Aptitude Tests.

These achievements are usually accompanied by impeccable recommendations by teachers and others. Recent noteworthy examples of residential state science talent schools include institutions in Alabama, Arkansas, Illinois, Indiana, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, and Texas.

Tamir (1989) surveyed scientists from 30 nations to determine how they attempted to serve the "gifted in science." He cited several nationally sponsored programs, particularly those in the former Soviet Union, which were fully described by Dunstan (1983), as well as a number of other national programs utilizing a variety of practices. In 1989, Israel followed another route, establishing a National School of Science and Arts (Zorman, 1987). Ringer summarized a discussion held among Gallagher, Passow, and Taffel on plans for the frame and aims of this school in the *Roeper Review* (1987, September).

Stanley has proposed a United States National School in Science and Mathematics along the lines of the Texas Academy of Science. Earlier, he wrote,

> I firmly believe that a residential state high school of science and mathematics should follow the lead of those prestigious programs [in the Bronx High School of Science and Stuyvesant High School] by preparing most of its students to compete in the Westinghouse Science Talent Search when they are seniors. To do less is to underdevelop the investigative scientific spirit of highly talented students. (1987, p. 771)

On the other hand, wrote Linder, principal of a heterogeneous school (Benjamin Cardozo in Queens, New York):

> Our task is to stimulate inquiry and discovery in all students and to provide opportunities for the more able to exercise their inquiry and discovery approaches on more sophisticated levels.
>
> All schools play a part in this mission. To isolate the supposed elite in residential facilities ignores what all of our schools should be doing. Is it feasible for secondary schools to develop science and math research programs? Definitely. (1987, p. 171)

(Table 3 records Cardozo's showing in the Westinghouse Science Talent Search.)

Considering the American interplay of schooling and education in family-school-community and cultural ecosystems; considering as well the delegation of the responsibility for schooling to the 50 states, it is probable that the organization of American schools for the talented and gifted will follow Cardozo's path more closely than Bronx Science's. Innovations that reflect different philosophical, educational, and ethical positions dictate considerable variety in aims and ends; hence, a variety of institutions within the symbiotic relationships of the family-school-community and cultural ecosystems will be necessary to enable expression of desired abilities.

City and state science high schools may still act as exemplars for various family-school-community ecosystems.

For the United States, is it desirable—and feasible—to have a national school? The rich potential of a *variety* of exemplars, interventions, and inventions to further abilities is congruent with an American creed. The function and success of *differentiated programs* for the science prone and/or talented in the local heterogeneous family-school-community ecosystem has been demonstrated.

The foregoing account of different exemplars should not obscure the obvious: While the family-school-community and its intereffective ecosystems furnish the ground of enabling environments, singular teaching and learning situations are central to producing environments that breed methods of intelligence evoking the potential of science prone young.

Teaching is the part of the ecology of achievement central to scientists' contributions to the culture. Somehow "science" as paradigm is often used as a category apart from the people who make it happen. The happening is a powerful act of intellection and purpose of those who are given to inventing the "human-made capital" upon which the new century will rest. It begins, however, with the young. "The occurrence of remarkable achievement within a field by a young child depends in part on the existence and transmission of highly evolved and economically communicable domains of knowledge," wrote Feldman (1979, p. 341).

The teacher (together with supporting colleagues) is required to become a researcher in curriculum and instruction, which s/he adapts to learners who have already achieved certain abilities. Some of these students are on the edge of discovery of new knowledge, coming to the differentiated curriculum already differentiated in their ability as students—therefore, in what they know—as well as in their prospective capability on the edge of discovery of new knowledge.

The terms "curriculum" and "instruction" take on different meanings with such young, because teaching and learning, particularly for the talented, is perceptible and intereffective, an interconnected circle of cause and effect. What is learned advances the development of a stubborn intellection, which in turn catalyzes further teaching and learning in powerful, cumulative, componential yet idiosyncratic directions.

Given the opportunity, the young begin to learn, as Szent-Gyorgyi is said to have remarked, "to see what everyone else has seen, but to think what no one else has thought."

New Curricular Constructs to Evoke Desired Abilities

As in any span of schooling, curriculum architects seem to have two problems: How both to maintain the valued constructs of past curriculums and to meld them with new aims, content, and methodologies.

Curriculums transposed into instructional materials flood the schools in changing forms. In the past 30 years, however, the basic constructs of knowledge that define curriculum in science—its paradigms—have been remarkably constant. My research into science instructional materials, whether formed into textbooks, computer programs, or inquiry procedures, shows curricular content cloned in conceptual structure.

The conceptual schemes and subordinate concepts basic to the study of the individual sciences developed by the various committees of scientists and teachers during the curricular reform period (1958-1962), first into curricular structures, then into textbooks, appear in the textbooks of present publishers with little modification. While the content has been updated, study shows that approximately 85-90 percent of the concepts explored are similar except in phrasing. The historical base remains similar; the additions are concerned with significant new discoveries. The conceptual thrust of standardized tests and the College Entrance Board Examinations also remains recognizable. Thus, the curriculums in biology, chemistry, physics, and geology, while using the basic concepts defined in the Sputnik era, have abandoned the approaches and rigor of the earlier materials. Some of the textbooks have been up-dated, however, particularly those of the BSCS, which plans a seventh edition of its blue version, *Biological Science: A Molecular Approach,* in 1995 (to be published by D. C. Heath in 1996) and the PSSC, whose text is now in its seventh edition (see Appendix A).

For the young in elementary school now, the course content as formulated in textbooks is similarly fairly stable. While videodisk technology and, at times, computers and hand-held calculators are becoming more and more common, their introduction changes the method by which information is delivered rather than what is offered. What is new, then, is instruction not curriculum. *If,* however, changes in design are introduced for the succeeding years of study—in the complexities of mathematical treatment, in computer-related inquiry (see later), or by the science prone's compacting of subconcepts or using college textbooks in rigorous high school programs—*then,* the curriculum would *actually* be augmented in content.

In a modified philosophical approach (and, therefore, possibly a changed epistemic or axiological emphasis) in curriculum and instruction, these *stable conceptual schemes* (Kuhn's "paradigms") remain in context within a newer view predicated by the culture. An emphasis on science, technology, and society would offer a different face to the curriculum, however. In an overall updated approach to science, the nuances of a changed philosophy and, thus, a new view of the function of science in culture and society, would call for an innovative instructional stance.

The curricular designs that follow make suggestions for developing a newer or modified framework for all students; however, for the science prone and science talented, the content will also need considerable amplification in advanced subject matter.

Trends in Curricular and Instructional Design

The aim to have the young do science is and was the essence of the idea-enactive, inquiry-oriented approach; it now appears in an instructional guise for all young in the postindustrial era. For example, in its new curriculum "Middle School Science and Technology," the BSCS notes that

> Many of the investigations are open-ended and encourage the students to design their own experiments or tests. Laboratory activities avoid simply verifying someone else's work and focus on investigations that require more student involvement. Thus, many of the investigations do not have single or explicit answers. . . . The structure of these activities avoids giving students the impression that there is one method that they must use or one answer that they must find in an investigation. (1992, p. 6)

The discussions in which I participated with other scientists, educators, and psychologists on the BSCS and the PSSC were clearly referential to prior curricular philosophy, including the views of Havighurst (1972) on "developmental tasks" and Phenix (1964) on "realms of meaning."

At present, science is taught according to three overall curricular designs—the pervasive exemplar with pull-out groups, fast-paced curriculums, and selective science schools—from which various state, city, or school curricular groups produce offshoots to try to meet the particular needs of their populations. In addition, teachers of the science prone seeking to help their students demonstrate talent should augment the chosen course of study, using the approaches suggested in this study and other interventions still to be devised.

Science, Technology, Society

Rachel Carson's *Silent Spring* (1962) was an early reflection of what science-based technology might do to the environment and the society it enfolds. On a more benign note, Harrison's presidential address to the American Association for the Advancement of Science likened schools, in their function as delivery services, to technology, in its enabling of students to correct and expand their knowledge and understanding both of the universe and of the achievements and failures of the earth's people (1984).

A number of publications have discussed the relationship of science, technology, and society. A collection of papers from *Science* (1949-1988) deals with the issue (Chalk, 1988), and the National Science Teachers Association has also considered them frequently, devoting its 1984 yearbook to the concept and issuing a position statement aimed at developing "scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision making" (1983, p. 109). In addition, its 1984 and 1985 yearbooks focus on science, technology, and society. The 1985 yearbook includes curricular and instructional strategies for a course on the subject, which parallels the approach of *Science for All Americans*.

Bybee, Harms, Ward, and Yager (1980) also treat science, technology, and society for the purposes of curricular planning, and Bybee (1984) sets forth the subject particularly vis à vis science education. The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology earlier (1983) came out with a similar position in *Educating Americans for the 21st Century: A Plan for Action for Implementing Mathematics, Science, and Technology Education for all American Elementary and Secondary Students.*

An immediate offshoot of these efforts is the full set of instructional materials for a new middle school curriculum developed by the BSCS and supported by a grant from the National Science Foundation. These texts on three levels, *Investigating Patterns of Change, Diversity and Limits, Systems and Change,* integrate life, earth, and physical science in the context of curricular themes emphasizing personal, social, ethical, historical, and technological issues through a variety of books and laboratory approaches (1994). The approach, based in explicit idea-enactive, inquiry-oriented group and individual laboratory experiences and supported by science kits and guides, may also be useful in augmented elementary school programs.

As a matter of fact, science prone students may use competent programs at any level in composite or compacted programs side by side with existing instructional materials.

New Curriculums Stretching PreK-12

The American Association for the Advancement of Science has been for almost a decade at work on *Project 2061,* a long-term series of publications designed to help reform the nation's science, mathematics, and technology education at all precollege levels. The Association recently published *Science for All Americans* (1989/1990/1994) and five panel reports (biological and health sciences; mathematics; physical and information sciences and engineering; social and behavioral sciences; and technology). Among other suggestions, the reports call for softening the boundaries between traditional subject matter categories and lessening the detail students must memorize. In addition, *Project 2061* has developed *Benchmarks for Science Literacy* (1993), which provides statements about how much knowledge—at a minimum—of science, mathematics, and technology students should have by the end of grades 2, 5, 8, and 12.

The recommendations made by *Science for All Americans* are based on this broad definition of science literacy,

> which encompasses mathematics and technology as well as the natural and social sciences [and which] has many facets. These include being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and way of thinking for personal and social purposes. (1994, pp. xvii-xviii)

These criteria relate directly to the "basic developmental tasks" and "realms of meaning" that shaped the work of the post-Sputnik reformers. So do the following *Project 2061* principles:

> **Utility.** Will the proposed content—knowledge or skills—significantly enhance the graduate's long-term employment prospects? Will it be useful in making personal decisions?
> **Social responsibility.** Is the proposed content likely to help citizens participate intelligently in making social and political decisions on matters involving science and technology?
> **The intrinsic value of knowledge.** Does the proposed content present aspects of science, mathematics, and technology that are so important in human history or so pervasive in our culture that a general education would be incomplete without them?
> **Philosophical value.** Does the proposed content contribute to the ability of people to ponder the enduring questions of human meaning such as life and death, perception and reality, the individual good versus the collective welfare, certainty and doubt?
> **Childhood enrichment.** Will the proposed content enhance childhood (a time of life that is important in its own right and not solely for what it may lead to in later life)? (1994, pp. xix-xx)

Science for all Americans offers, thus, a guide *for* instruction (curricular suggestions) and a plan *of* instruction (strategies and tactics) correlative with the developmental tasks aimed at sustaining its philosophical, educational, and psychosocial thrust. While the questions and criteria apply to *all* Americans, these broad guidelines may be augmented for differentiated curriculums.

Presecondary Programs in Current Use

As indicated earlier, a plethora of textbook series are available for students K-9. Their conceptual-schemes bases are virtually identical to each other and to those written in 1958-1962; they sometimes differ, however, in narrative, in laboratory experiences (and lab manuals), and most of all, in providing computer-assisted problem doing and problem solving activities. Almost all include kits of laboratory materials, make reference to films and videodisks, and are accompanied by filmstrips and computer disks. Publishers generally offer information and assistance in using their materials, often employing former teachers to demonstrate lessons and different approaches. Schools may, usually with help from science education staff of the neighboring city, county, state, college, or universities, make appropriate modifications of scope and sequence for advanced study by the science prone.

As noted, reformers are once again beginning to understand the importance of energetic elementary school science programs, aiming at scheduling at least 40 minutes of science every day with augmenting resources as appropriate. This effort parallels that of the building of elementary school programs during the Sputnik years.

A Curriculum Thrust Connecting Disciplines for Middle and High School Students

The National Science Teachers Association's *Scope, Sequence, and Coordination* secondary school project (begun, 1990, and continuing) has proposed a revised science curriculum for grades 6-12 (1992, 1993). Essentially, it coordinates conceptual schemes in biology, earth science, chemistry, and physics, and laboratory activities in *each grade.* The project, with generous funding from the Department of Education and the National Science Foundation, is developing and implementing, at six centers nationwide, an instructional sequence that not only increases but also integrates the study of biology, chemistry, physics, and earth and space science across the secondary years. As students mature from 6th to 12th grade, the emphasis of science study gradually shifts from descriptive and phenomenological to empirical and quantitative to theoretical and abstract. Thus, no year of study is given over to a single science. Yearly courses in biology, chemistry, and physics are eliminated.[14]

The intent and design of content and hands-on activities of the proposals of the American Association for the Advancement of Science and the National Science Teachers Association are at present unaccompanied by instructional materials—textbooks, films, computer data bases, and the like. Instead, the proposals are intended to guide and assist teachers and curriculum designers in identifying instructional materials consistent with their purposes. The *Scope, Sequence, and Coordination* project proposes in part that, "As change occurs in science education, textbook publishers will redesign their offerings, pilot sites will develop instructional units, and experts will create data bases describing educational materials. The *Content Core* (1993) provides criteria to evaluate the suitability of these new instructional materials" (p. viii).

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[14]Some years ago (1977), I suggested a similar cross disciplinary approach for science in the elementary schools. The conceptual structure of the curriculum I described, while laid out for convenience in a framework that corresponds to the school year, day, period, and sequence (grades 1-6), does not, as I wrote then, "fix the teacher or the student into a rigid curriculum. On the contrary, it gives the teacher freedom to plan a variety of experiences, and it gives the students freedom to plot their own experiences" (p. 23).

Such a curriculum—at *any* level of schooling—lends itself admirably to the process of augmentation for students who select themselves as science prone or talented.

Like the Sputnik reforms, *Scope, Sequence, and Coordination* is based on constructivism (concept seeking and concept forming) and in inquiry-oriented teaching and learning. It does not lend itself, according to its authors, to traditional multiple-choice testing. The National Science Teachers Association developed this curriculum because of its view that "the typical U.S. science program discourages real learning not only in its overemphasis on facts, but in its very structure, which inhibits students from making valuable connections between facts." In pressing its interconnected curricular design, the introduction to the *Content Core* states that,

> most science programs in U.S. secondary schools are organized in what is commonly called "a layer cake." Students study biology in the ninth or tenth grade, then chemistry the following year, and finish with physics in the 12th grade. In a single year, students pursue one discipline from the descriptive to the theoretical, with little reference to prior science experiences—either in that course or other science courses—and even less reference to upcoming science experiences. One consequence is that many students never participate in those future science experiences: Three-fourths of American high school graduates do not take science after the tenth grade (or, in layer-cake terms, after biology). The emphasis on facts and rote learning and the difficulties students encounter in grasping theoretical considerations without a grounding in experience deter many from continuing in science. (p. 2)

Other Reform Thrusts

While the American Association for the Advancement of Science and the National Science Teachers Association have been early and important players in the current explosion of science reforms, they have by no means been acting in a vacuum. The standard-bearer, which has set benchmarks for much of the present reform activity in scientific and mathematical fields, has been the work of the National Council of Teachers of Mathematics on its much-praised *Standards* for curriculum (1989) and teaching (1991). Currently underway is a cooperative effort by the Council and the Mathematical Sciences Education Board of the National Research Council (1993) to reform assessment; although their work obviously focuses on math, it sets a path for other reform efforts that include but reach beyond mathematics to suggest similar requirements for meaningful testing—assessment, ideally, that *teaches* as well as measures—in relation to educational improvement. Some suggestive examples appear in *Measuring Up: Prototypes for Mathematics Assessment.*

Although the National Council of Teachers of Mathematics' work on the *Standards* began long before the 1989 Education Summit, their publication was particularly timely. The National Science Education Standards and Assessment Project, commissioned in 1991, has as its goals to develop science education standards for grades K-12 and to build consensus among a range of constituencies nationwide to put those standards in place. The National Research Council was asked by the National Science Teachers Association, the Department of Education, the National Science Foundation, the National Education Goals Panel, and several scientific societies to develop standards for science education along the lines of those successfully proposed and disseminated in mathematics. In late 1994, the Committee solicited comments on its widely disseminated nearly 400-page draft document suggesting precollege science standards for curriculum, teaching, and assessment.

In addition to the Science Standards project, other major federal initiatives are aiding science education, all stressing learning as a continuum from prekindergarten through higher education, and all calling for an equitable approach that will serve all students. They include—but are not limited to—the following efforts.

- The Department of Education's Dwight D. Eisenhower Mathematics and Science Education Improvement Program was designed to support innovative programs of national significance that improve the quality of teaching in those fields and to increase all students' access to that instruction.[15] Both national and state Eisenhower programs focus on teacher training and curriculum change, K-12, and seek not only to continue ongoing improvements in mathematics and science education (and—as of 1994—other precollege subjects as well) but also to develop new models of change and reform for programs in a broad range of urban and rural school systems. Nearly a third of the nation's math and science teachers had by 1994 in some way benefited from Eisenhower grants. National Eisenhower grants (roughly 5 percent of the $251 million appropriated in 1994) are awarded competitively. Most of the remaining 95 percent, in state Eisenhower funds, goes to districts on a formula basis reflecting the number of students and the income level of their families. If they apply, all school districts are entitled to their portion of these funds.

- The National Science Foundation's Statewide Systemic Initiatives in Science, Mathematics, and Engineering Education currently funds innovative programs in 25 states and territories; the Urban Systemic Initiatives support reform in 9 cities; the Rural Systemic Initiatives are in planning stages. The Foundation awards $2-3 million annually over a five-year period to comprehensive programs working for fundamental changes that result in coherent mathematics, science, and technology education for kindergartners through college-aged students. Funded states and cities have proposed reform and change of curriculum, instruction, assessment, teacher preparation, and staff development, as well as innovations in policies bearing on accreditation and certification. Through support of integrated, cooperative changes, these programs are designed to broaden education's impact, to accelerate its pace, and to increase its effectiveness. The Initiatives stress coordination of local, state, and federal efforts. From the governor's (or mayor's) office, through higher education's structures, through teachers' organizations, school boards and PTAs, museums and businesses, the Initiatives integrate with federally funded projects in many departments of the U.S. government.

- *The National Science and Technology Council,* which comprises representatives of 16 federal agencies and 3 executive offices (the Office of Science and Technology, the Office of Management and the Budget, and the White House), has compiled a comprehensive baseline inventory of federally funded programs that affect mathematics and science education at all levels—precollege, baccalaureate, graduate, and beyond. Since 1990, the Council's predecessor, the Federal Coordinating Council for Science, Engineering, and Technology, began to work actively for increased cooperation and coordination of math and science education initiatives across the government.

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[15]The Eisenhower Program was authorized in 1989 for $130.5 million with steadily climbing funding increases since then. It was reauthorized for fiscal year 1995, as the Eisenhower Professional Development Program, under the Elementary and Secondary Education Act, for $800 million and expanded to cover all the core curriculum subject areas described in the 1994 National Education Goals. The emphasis on mathematics and science retains, however, what the Department of Education's Daniel F. Bonner, director of the School Effectiveness Division and head of the Eisenhower State Programs, calls—echoing Shakespeare—"pride of place."

In this collaborative framework is the ground-breaking Memorandum of Understanding, signed February 5, 1992, by the Department of Education and the National Science Foundation—two agencies formerly frequently at loggerheads—and calling for joint action to implement systemic reform nationwide. The Council's Committee on Education and Training Research and Development is working on strategic plans for 1995-1999 and 1996-2000 to improve science, math, and technology education.

In addition, the Washington-based *National Science Resources Center* is building a nationwide network of teachers, school administrators, scientists, and others interested in improving precollege science study and compiling a collection and computer data base of science teaching materials. Operated jointly by the National Academy of Sciences and the Smithsonian Institution, since 1985 the Center has been disseminating information about teaching resources, science education programs, and other sources of expertise and assistance. Under the rubric of *Science and Technology for Children*, it provides a series of primary school materials that are classroom tested, scientifically sound, and reflective of current theories about how children learn. Finally, its outreach program offers institutes and conferences designed to build consensus and leadership among scientists, engineers, and school district staff.

A Clarification of Purpose

All the approaches to reform just described furnish at least three clear positions to those who frame explicit curricular and instructional designs.

- First, curriculum and instruction should advance the scientific literacy of the young. The imperatives of this issue are stated in clear, unmistakable aims and ends.
- Second, teachers and learners should be involved in activities that join science and technology to relevant social issues. In this, the newer technologies of science education—calculators, computers, interactive videodisks are vital.
- Third, the needs of various populations of students—namely females and underrepresented minorities—often lacking scientific literacy are brought into focus. (On this, see the BSCS [1993] on four levels of biological literacy from the nominal facility students bring to the first class through functional [describing with limited understanding], then deepening into structural and, finally, multidimensional knowledge.)

All the frameworks stress the idea-enactive, inquiry-oriented mode of teaching and learning—postulated here as central to instruction for *all* young—that enables the science prone to identify themselves for advanced study. Particular refinements of course content and approaches for the science prone fit readily in fast-paced and originative augmenting frameworks. Fast-paced subject matter in elementary school can lead to originative inquiry in the high school years.

The Role of the New Instructional Technologies

In a useful paper on the role of the computer as a catalyst to an active approach to teaching and learning, Collins (1991) holds that computer-assisted instruction calls for teachers to be "facilitators who help students construct their own understandings and capabilities in carrying out challenging tasks. This view puts the emphasis on the activity of the student rather than the teacher." Increased computer-assisted instruction, he believes, will both lead to and necessitate some or all of the following (benign) changes:

A shift toward more engaged students and a shift from

- whole-class to small-group instruction
- lecture and recitation to coaching
- working with better students to working with weaker students . . .
- assessment based on test performance to assessment based on products, progress, and effort
- a competitive to a cooperative social structure
- all students learning the same things to different students learning different things[16]
- the primacy of verbal thinking to the integration of visual and verbal thinking (p. 29)

In the light of these "informed speculations" based on documented research, Collins notes that "any restructuring of the schools can take place only over an extended period of time"—and he proposes a long-term view for the introduction of computer technology.[17] He states further that both Cohen (1988) and Cuban (1986) have "argued persuasively that computer technology is likely to have little effect on the schools" and quotes them as asserting that, to the "degree that technology is flexible, it will be bent to fit existing practice and that, to the degree it cannot be bent to fit existing practice, it will not be used" (p. 31).

Whether Cuban and Cohen's prediction is borne out may depend on whether computer-assisted instruction remains an innovation that in the short run helps modify instructional practice in teaching and learning to advance desired abilities or whether it develops into a generalized movement. If the former, it is likely to have limited function in the classroom and laboratory; if the latter, its impact could be considerable. (See my discussion on the course of formerly innovative classroom technologies such as TV and programmed instruction [1981, pp. 40-56.] While they did not become movements, they remain as residual methodologies.)

A majority of the "informed speculations" Collins (1991) offers fit with the approaches that catalyze science prone students in individual and small group investigation—whether exploratory or in originative inquiry. Certain papers offered by students in the Science Talent Search might not have been possible without computers help in saving time, in gathering data, in analysis, and in synthesis. Nickerson and Zodhiates (1988) provide a useful analysis of computer-assisted instruction in *Technology in Education: Looking Toward 2020*. Papert (1980) has also made a clear case for computers, partially because of children's fascination with them. This technology can stimulate children to undertake inquiry beyond expectation. Lepper (1985) and Linn (1986) also suggest the use of computers to establish a research base for science education. Future research may well find computers useful to help the artisans so necessary to research in science and technology.

Computer-assisted instruction may also offer a promising opening for gifted underachievers in science. At promise as good students, they sometimes seem to find blocks in translating their giftedness into the kind of behaviors that characterize students with able learning and independent study habits.

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[16]And a subsequent decreased reliance on standardized testing.

[17]Similar speculations generally ramify the literature about computer-assisted instruction.

During my work in helping to develop programs aimed at the science prone in sixth-ninth grade classrooms, I observed a new level and cast of idea-enactive, inquiry-oriented teaching and learning in various stages of computer-assisted instruction. I made extended observations of six full eighth-grade lessons (one in mathematics and five in science)—much too small a sample for any conclusions.

The very preliminary data, however, look promising: Not only the high-ability, high-achieving groups benefited from computer-assisted instruction, but also teachers expert in its use reported that young previously considered underachievers because of relatively high IQs (120-125) and low grade point averages may have been "turned around" by their work with computers. Teachers indicated that the underachievers' formerly "distracted behavior" became "focused" in the problem-solving mode with the aid of computer and videodisk technology. The "attention-riveting" (as one teacher described it) potential of the highly feasible interactive videodisk techniques in utilizing visual sequences in observation was readily observable.

This technology can make possible in the classroom instant observations of phenomena that in reality might take a great deal of time. For example, certain educational technologies show animal or plant behavior, molecular interactions (in animated cartoon), a scientist's explanation of a physical or biological phenomenon, or the entire course of an experiment. At any point that seems optimum, the teacher can make a strategic stop of the procedure for questions and discussion and then proceed further. The learning behaviors I watched seemed as stimulating, steadying, and productive as those reported earlier in idea-enactive, inquiry-oriented teaching and learning. In three of the middle schools I observed, computers had begun to assist teachers in forming a combined science-mathematics curriculum. Perhaps Whitmore's Cupertino experiment with differentiated classes for underachievers (1980), as well as Supplee's (1990) initiatives, might be reinstituted utilizing the newer technologies available.

An aid to empirical researches on gifted underachievers may be at hand. Prior to 1976, the teaching I observed was relatively computer free, both in full class and resource rooms. Up to then, computer-assisted instruction had been introduced only sporadically. Between 1983 and 1986, as Collins (1991) has noted, computer-assisted instruction procedures, including interactive videos and a new element—simulation experiments—were in full classroom use in a number of schools. These techniques are increasingly available in both high schools and middle schools. (The plan for instruction in the new BSCS science and technology curriculum for the middle grades [1994] is particularly noteworthy.)

Computer-assisted instructional technology may—or should—fill the vacuum created by the present lack of laboratories in the middle school. This approach could make possible learning through observation and manipulation of simulated phenomena—an effective substitute for observation even alone but particularly valuable when used for actual problem solving to accumulate hands-on, brains-on, minds-on, data. Papers in Sheingold, Roberts, and Malcom (1991) address the use of computers in breaking the barriers that relate to language disabilities and the range of learning styles created by social, ethnic, and cultural diversity. Several contributors demonstrate the computer's power in the laboratory in combining mathematics and science. In an earlier paper on the uses of computer-assisted instruction, Malcom (1988) emphasized, "If we have a tool that helps students overcome previous disadvantage and reach their educational potential, we have a moral obligation to give priority to this purpose" (p. 229).

The newer approaches to science (modified to fit populations of the science prone) plus the newer technologies may open wider opportunities for more members of the science talent pool.

A Jointly Planned Curriculum for the Science Prone

Teachers with the happy task of planning a curriculum for the 10th grade science prone (possibly, eventually, the science talented) have a wide latitude. Proved in scholarship, these adolescents, self-selected for the program, devour the information in school and college instructional materials. Some will take the route of concentrated advanced placement courses. Others will choose the deeply augmented course combined with originative work. Still others separate the course and the research, doing one in a semester year; the research during planned time and summers. (On this see descriptions by Brandwein, Morholt, & Abeles, 1988; Eilber & Warshaw, 1989; Kopelman, Galasso, & Schmuckler, 1989.)

At Forest Hills High School in the 1940s and 1950s, some of the teachers in the department I chaired joined me in taking the opportunity to engage energetic and like-purposed but idiosyncratic students in modifying the scope and sequence of an unplanned, expanding overt curriculum. After the fourth year of teaching classes for science prone young, it turned out to be not only possible but also both practical and immensely rewarding to engage the students in developing a plan for the year's study.

In the biology class described here, we discussed the potential course work from the first day, and students were asked to suggest their interests. The scope, the flood of topics, concepts, ideas, and interests filled a full side of the classroom's chalk board. In responding to the question: "How would you organize these concepts or ideas so they might be interconnected?" students showed themselves to be sensible and sensitive organizers. We then developed a conceptually based study.

Once given a sense of structure in the conceptual schemes that generally define a discipline, the students—in discussion with me serving not as an authority but as a member of the class—clarified the structure and meaning of the conceptual schemes (in subconcepts). Then, in self-selected groups, the young took a week to study a variety of sources—including school and college textbooks, other books and references, laboratory manuals, and the New York state syllabus of expected competencies.[18] As a committee of the whole (including me as a consultant), the class put together topics—in concept-centered terms—into a course covering content appropriate for a first year of college study. Given the number of school days within the academic year, however, the students realized that they had been too ambitious.

In further discussion with the students (but serving now as head of the committee of the whole), I suggested which concepts called for wide discussion, which ones might be given over to independent study by individuals and groups, and which ones would best be accomplished with the aid of specialized equipment in the laboratory. All three types were treated in the ample school library of specialized and college-level textbooks and filmstrips. Appropriate instructional materials, if not already available, were ordered (the librarian attended several class discussions). Students were also encouraged to make use of area public and college libraries. Within the following week, most students had chosen their

[18](New York state prepares a syllabus in a number of areas, including science, which students are expected to master for the annual Regents' examination; thus, the students had to "cover" the materials it required.)

independent-study library research and had already given up their free study periods in order to proceed with their, as yet unselected, research problems.

At Forest Hills, students planned such courses in alternate years, following a preplanned curriculum in the others. Both groups had similarly high grade point averages (in the top tenth of the class) and scored in even higher percentiles on the Regents' examinations. Between 1944 and 1954, Forest Hills produced as many Science Talent Search winners as the selective Bronx High School of Science and Stuyvesant High School (17 in each case) and more runners-up than Stuyvesant (see Table 5). These data indicate that independence training and independent study—even a certain latitude in course content—do not stand in the way of achievement in desired abilities.

The Hidden Curriculum: A Differentiated Class for the Science Prone

Committed to a specialized curriculum—as are other students who select music, art, or advanced social studies—the students in the course just described selected a course that provided certain engagements necessary to nurture individual potential in science. A covert or hidden curriculum flourished as they immersed themselves in learning environments created for personal fulfillment and the pursuit of their special excellence.

According to Passow, in such a hidden curriculum,

> Self-concepts, values, attitudes, ideas about excellence, willingness to pursue particular lines of inquiry, task commitment and perseverance, and other affective and cognitive behaviors are some of the things which students learn from each other and from the classroom and school environment as well as the larger community of learning. (1989a, p. 29)

In their acts of originative inquiry, these young began to see themselves not as learners doing laboratory problems leading to preplanned conclusions but as participants following the behaviors of the scientist. In the present, they caught a vision of the future. It is wondrous to see a student who has discovered a hitherto unknown fact. Possibly she or he has uncovered new knowledge (if verified). The symbolic "walking on air" inadequately describes the child's growth in stature.

A Possible Scenario—1991 to 2061

Is it possible to sketch the prospects of the science talent pool just forming? Say, the rites of passage into the first grade were in 1991; thus, those in the science talent pool would move into universities 10 to 12 years later (2001-2003). Some benchmarks, past and future, are from the early days of *Project 2061:*

> The first phase of this study will be conducted during 1986, the year in our lifetimes, as it turns out, in which the most famous of all comets will be nearest to the earth. The children born that year will, on average, enter school in 1991, graduate from high school in 2004, enter the job market between 2005 and 2015, have children who start school in the 2020s, run things for two or three decades, retire from work in the 2050s, and live to see Halley's Comet when it returns in 2061.

> What we do as a nation during the next five to ten years to reform education will affect an entire lifespan. (American Association for the Advancement of Science, 1985)

The scientist and philosopher, Jacob Bronowski (1956) would add that both young and old will share that responsibility—for together they may know what is known, or where to find it. And it is a lifework that they will share; for scientists and scholars do not generally retire even upon the happy event of Halley's Comet. And their works—in the continued skein of problem and solution—will weave their way into unscheduled years in new generations to come.

Summary, Discussion, and Implications

Curriculum and Instruction to Evoke and Identify Abilities in Science

Curriculums transposed into instructional materials flood the schools in changing forms. However, in the past 30 years or so, at least the basic conceptual schemes that define curriculum in science—its paradigms—have been remarkably constant. My research has shown that precollege science instructional materials, whether formed in textbooks, computer programs, or initial inquiry procedures, have been cloned in conceptual structure from the curriculum structures (made into textbooks) created by the various committees at work during the curriculum reform period (1958-1962). Approaches created by scientists and teachers of the Sputnik era still appear in the textbooks of present publishers. Content has been up-dated, but 85 to 90 percent of the concepts and subconcepts have changed only in phrasing. The additions concern new discoveries and cycles of crises; the rigorous treatment has diminished, however.

This pattern holds for grades K-12, except where videodisk technology and, at times, computers and hand-held calculators have been introduced. Future changes in design for the science prone may occur in great part by augmentation through the new possibilities of integrated mathematics and science made possible through computer-assisted instruction and inquiry. Such enrichment could also take place through the compacting of subconcepts or through college textbooks used by the science prone in rigorous high school programs.

Any discussion of teaching and learning as identifiers of the gifted, science prone, or science talented must take into account the limiting environments that inhibit the evocation of abilities. The goal is to ameliorate these conditions through the reforms planned for completion in the year 2000.

In sum: Differentiated programs are necessary for evaluation and identification of science prone and science talented young because special curricular and instructional devices are favorable to cultivating and evoking desired abilities. Whatever the mode of selection of qualified students, their *performance* in an enabling environment differentiated to fit various abilities and skills is the most valuable identifier of future ability in science, whether expressed by the scientist or the artisan to be.

A Triad of Programs

Curriculum and instruction in science can evoke desired abilities and methods of intelligence in three ways:

- excellence in the middle school years as measured by achievement tests in a program demanding fast-paced subject matter in science
- successful performance in research ability, a work in originative inquiry, coupled with a reasonably high acquisition of knowledge within the context of a demanding course of study
- demonstration of abilities before graduation from the pervasive high school curriculum through high Scholastic Aptitude Test scores and strong performance on College Board Achievement tests in particular sciences

This last cohort of able students come from college preparatory programs (often coupled with acceleration and enrichment), which provide curriculum and instruction in science and mathematics, as well as in verbal skills. Such programs usually offer honors courses, scholarships, and Advanced Placement programs. Although most of these students are eventually tested in demanding college and university course work, those participating in originative inquiry have been part of specific follow-up studies[19] that demonstrate that research abilities can identify future science talent. Youthful success in originative inquiry appears to be a criterion sample through a work. It is also demonstrable, however, that the great bulk of scientists in the past were trained under the aegis of the pervasive exemplar—usually the only one available to them in high school—and scored high on initial precollegiate measures of ability and achievement.

Two questions. One: What if curriculum and instruction were planned throughout the first five to seven years of instruction to encourage students demonstrating first signs of science proneness so that they—fully understanding the nature of the program—were free to select

- fast-paced study or
- originative inquiry or
- or both (with the fast-paced first)?

Two: What if qualified teachers were available and curricular and instructional modes and materials were adapted to support early augmenting programs for the science prone?

Perhaps we could then begin to evaluate not only the intellective factors but the nonintellective ones as well and, where appropriate and possible, to plan corrective measures. And we might well begin to understand what really goes into the making of a scientist. For the future contributions of the young who selected themselves for the program would also need to be probed. In the end, whatever the prior curricular and instructional history, the student would be judged not only by a credential but by a life work in research, that is, by the desired ability of the scientist.

A Dyad of Methodologies

As the objectives of the curriculum in science are dissected, two functions generally appear: The acquisition of knowledge and its modes of capture. Curriculum (generally, what is to be taught) and instruction (how it is to be taught) are relevant but distinct fields forming a dyad.

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[19]My studies of self-identification of science talented students had a dry run in 1937-1939, an evaluation in 1942-1943, and culminated in my 10-year study 1944-1954, when desk-top computers were simply not available. Nonetheless, one student at Forest Hills High School (New York) did his research study on an IBM 701 computer using IBM facilities (1954). See *The Gifted Student as Future Scientist* (1955/1981, pp. 101-102).

On the one hand, a curriculum is generally the formulation of a committee, which often reduces complexity so that students may grasp a concept and amplify it in continuing study. Thus, a curriculum is often a subtle introduction to the culture. For the science prone or talented, the fixed curriculum is not easily managed because such young soon surpass its limits; thus, their curriculums need to be eminently flexible. Often, the science prone modify the curriculum as they advance, amplifying concepts into conceptual schemes, questioning, discussing, bringing problems to light. The science prone need the family-school-community to provide a bank of available resources. In addition to laboratories and other offerings of nearby colleges, work with a mentor may be necessary. Computers, data banks, videodisks, software, and other technologies should be available in addition to the print materials.

On the other hand, teaching is a personal invention, based in hard-tried experience, training, and professional background in the field. Teaching also requires a framework of psychosocial knowledge and understanding. For instruction is a daily interpersonal relationship between teacher and young. A wide latitude in redefining content in relation to expressed abilities is necessary for the science prone.

In any event, my wide-ranging research has not uncovered studies validating the stated claims and/or purposes of a given curriculum. In the case of curriculums designed for the science talented, instruction is apparently taken as a measure of the effectiveness of the curriculum without determination of the contribution of students.

My observations in the field, particularly in high school science, showed that, even while curriculum content was upgraded, the mode of instruction generally remained fixed in a lecture-textbook approach (often based in a rhetoric of conclusion). The marks are recognizable: laid-out demonstrations and laboratories (where available) with preplanned manuals directing the student to a conclusion within the class period. The idea-enactive, inquiry-oriented approach was generally approved in descriptions of effective science instruction in teachers' professional science books (and sometimes used in college methods courses), but in high school classes, the lecture-textbook laid-out laboratory dominated.

In short, in the case of the science talented, the teacher and students reinvent the curriculum as they proceed. The dyad of curriculum and instruction as enabling environments for talented young then needs to be as innovative as are the young who will benefit from it. For they may change its future form and function.

A Triad of Ecosystems

When I speak of differentiated programs as essential to the teaching and learning environment of the science prone on the road to talent, I address multifactorial, intereffective quantities and qualities not easily dissected statistically. For example, many limiting environments are neither readily separable from each other nor severable from the overarching ecology. Once resources become limited, schooling suffers for everyone, but especially for the science prone. They often need the capital equipment of the sciences (laboratories, microscopes, oscilloscopes, computers, metric devices, calculators, and the like); perishable materials and equipment (live materials, chemical equipment, and substances); as well as up-to-date textbooks, journals, fully equipped libraries, films, videodisks, and duplicating machines.

If it is obvious that programs for the talented require additional resources, it is equally obvious that schooling in general requires equality in funding for all the family-school-community ecosystems. The National Goals 2000 project will not succeed without additional funding (a drumbeat in the Carnegie Reports [1991, for example] as well as *A Nation At Risk,* National Commission on Excellence in Education, 1983).

The total program incumbent on teachers of the science prone makes it obvious that substantially more funds are necessary. Not only boards of education but also the community, state, and national resources need to join to augment curricular and instructional needs. Hence, the mutualism of community-school and cultural ecosystems are the underwriters of a differentiated program. The efforts of the third postsecondary ecosystem need to dove-tail with the other two ecosystems to smooth the journey of the science prone en route to an expression of a science talent—before and after completion of a science talent pool. But the process of energizing the ability of the young who will become scientists begins in the home, classroom, laboratory, and project room.

To reemphasize, the interconnectedness of the ecology of achievement in which the young find themselves from the rites of passage from home to schooling and to further education needs careful reexamination. The loss from the science talent pool needs stemming not only during the school years (particularly in the high school) but in the early college years as well.

Inferences

An environment in which the young discover for themselves, whether through the guided discovery of teachers or the initiative of science prone learners, is part of idea-enactive, inquiry-oriented teaching and learning, an approach that counteracts the syndrome of 10 inhibiting enabling curricular and instructional practices. Further, the idea-enactive, inquiry-oriented teaching model engenders activities that can and do serve as identifiers of science proneness in the young.

Three inferences follow:

- First, the structure of curriculum and the mode of instruction in classroom and laboratory serve to identify science proneness, an understanding that suggests a significant way to increase the science talent pool.
- Second, the widest net ought to be flung to open opportunity for all young in an idea-enactive, inquiry-oriented learning curriculum and instruction. This generous cast offers access to equal opportunity for self-identification, *along with but not exclusively through ability and achievement testing,* as composite factors for entry into the science talent pool.
- Third: Exemplars distinguishing three schools of thought indicate science proneness and/or science talent: a) fast-paced instruction (earlier than usual exposure to courses) with abilities measured in achievement testing; b) originative inquiry as an in-context measure resulting in a work considered to be a criterion sample of prospective science talent; c) the pervasive exemplar of curriculum and instruction in U.S. high schools, with augmenting modes in acceleration and enrichment, scholarships, and rewards.

This last (college-preparatory) model now furnishes most of the cohort composing the science talent pool and remains the matrix for present innovations in schooling. The fall-off of young with interest in science before graduation from high school and after the freshman year of college, however, is a definite cause for concern.

A newer model suggests itself. It modifies the pervasive exemplar, making provision for a differentiated curriculum and mode of instruction suited to the needs of the science prone and leading to the expression of science talent. Select science schools are increasing in number as are select programs for the science prone in heterogeneous schools.

New frameworks in curriculum, as well as new technologies, are available, but all will require modification and augmentation to fit the abilities of the science prone on their way to demonstrating talents. New technologies in science education promise certain advances in independent study and inquiry-oriented teaching and learning.

The preparation of present programs, defined by the National Education Goals and designed to augment abilities in science and mathematics as well as to secure an increase in the science talent pool by the turn of the century, is only beginning. Noted throughout this study are national and local initiatives calling for an increase in resources to support the capital expenditures needed for the teaching of science—as well as the need for a full complement of teachers skilled in science and mathematics.

At the Apex of the Ecology

The ecology of achievement (the sum of activity of the three ecosystems working in harmony) that produces and nurtures the researcher in science is also in question. A recent sounding on the present state of affairs, reminiscent of Lederman's early warning, comes from George Bugliarello, President of Sigma Xi. His editorial in the *American Scientist* (1992) notes:

> Young researchers today face greater difficulties than their older colleagues encountered. . . . This state of affairs is not only an ordeal for the individual researcher; it is also a squandering of a pivotal national resource. The preparation of a research scientist or engineer takes years of investment by society—family, teachers, taxpayers, philanthropists, government—in addition to the researcher's own hard work and personal sacrifice. . . . There can be little doubt that the researcher will be even more essential in the next century, as information in the social, biological and machine domains becomes the preeminent instrument of progress. . . . Our society needs to recognize what a precious, irreplaceable resource a researcher is—a resource to be carefully husbanded. A researcher is not a commodity. (p. 412)

Construct V: Enabling Achievement—Designed for Early Self-Identification of Science Talent

Construct V proposes:

- to suggest a mode by which students identify and select *themselves* to participate in differentiated programs of demanding study culminating in long-term originative inquiry
- to report observations of the young in the activities of inquiry to identify certain correlative behaviors
- to argue that, by submitting their work to examination and external evaluation by qualified scientists, students experience the peer review and tests of validity to which works in science are traditionally subjected

This construct will also define a working exemplar encompassing these purposes. Originating in the late 1930s, this exemplar has gained support through usage and has accumulated a weight of evidence through constant evaluation. Study of this exemplar's analysis, synthesis, observations, and findings supports recent theories and findings.

When the young enter into the climate of science, they should benefit from at least two resources as gifts of schooling: First, they deserve access to the *substance* of science, a rich, even massive, conceptual structure of cumulative knowledge. Second, they deserve opportunities to participate in problem finding and concept seeking and forming—that is, to experience the *style* of science—its particular modes of inquiry and explanation. With these twin thrusts in mind, in the 1930s, 1940s, and 1950s, I organized curriculum and instruction encouraging the acquisition of advanced, rigorous, structurally organized knowledge, along with its companion, originative inquiry. Students solved unknowns through commitment to long-term individual probes.

My convictions about the essential value of originative inquiry programs to high school instruction in science grew from my own early experience in scientific research. The disparity between school science education and the working world of the scientists who taught me when I was young and brought me to the adventure of inquiry was apparent. I tried to set up a secondary science program close to the reality of working scientists and found that certain young—not all—were eager to give it a try.

At George Washington High School in upper Manhattan and at Forest Hills in Queens (both heterogeneous public high schools accommodating all students in their residential area), I made trial-and-error attempts to develop a differentiated curriculum and mode of instruction to give full opportunity to the capacities of a variety of students attending a general high school. Some planned on college; others had other goals. We outlined the program at George Washington High School (1937-1940), later took it on a dry run there (1942-1944), and then used it experimentally at Forest Hills High School (1944-1954). Our program saw its fullest development at Forest Hills, and I was able to offer a first hypothesis (1947), a theory I developed more fully in the ensuing years as a result of continuing study (1951, 1955/1981, and 1988).

About the same time that we were at work at George Washington, Morris Meister had been planning a specialized school, the Bronx High School of Science, which opened its doors in 1938 (Meister & Brandwein, 1958; Meister & Odell, 1951). Stuyvesant High School had by then also become a science high school. Prior to the institution of their plan in the 1940s, Edgerton and Britt had spent a number of years working with Science Service to create a method by which originative inquiry could be used to measure science talent. The result, the Westinghouse Science Talent Search, initiated in 1941, was brilliantly managed by Watson Davis and his colleagues at Science Service (Washington, DC).

In 1957, Passow laid down the principles of a differentiated curriculum for the gifted, in schooling in general as well as in science in particular, concepts he expanded in 1989. The programs Passow proposed were based in the conviction that many discoveries in scholarship and science work to advance practice, knowledge, or process in a given field not as "singletons," but as multiples (Merton, 1965/1985). Such discoveries may themselves be the result of what Sternberg called "triarchic" mental functioning: He wrote,

> Behavior is intelligent to the extent that it is (a) used in adaptation to, selection of, or shaping of one's environment; (b) responsive to a novel kind of task or situation or in the process of becoming automatized and (c) the result of metacomponential, performance-componential, or knowledge-acquisitive functioning. (1985, p. 319)

That is, people behave intelligently if they can choose and form their surroundings, face and meet new challenges quickly, easily, almost without thinking about them, and internalize their learning to apply in future doing and knowing. (Sternberg's descriptive words for this facility and flexibility are "nonentrenched" and "automatized.")

Antecedents to Identification

In the heuristic modes of research scientists in the laboratory, one is simultaneously impressed by the ready, steady flow of critical thinking and by sudden flashes of insight. Informed by voracious reading of past cumulative knowledge, working scientists are idiosyncratic in attitude and inventive in procedure. They embody the characteristics of early independence training, feeling free to use any honorable method or device to yield a verifiable hypothesis or experimental procedure. Scientists are wide conceptualizers and categorizers, speculating and trying out ideas, concepts, and blue-sky preconceptions. They consult and experiment with plans of procedure among colleagues, superiors, and apprentices to get a fit of hypothesis to the mêlée of inquiry.

To sustain in the schools the environment of critical thinking typical of scientists' general practice of teaching and learning, questioning was superior to the declarative mode, that is, to information provided through sustained lecture. Students were expected to do independent study, a practice that well-prepared them for the questioning-discussion-colloquium approach in which they would be contributors, ready to probe the evidence at hand. The laboratory was almost always scheduled in advance of the discussion; thus, it became an initial problem-solving approach towards what Conant (1952) calls "well-ordered empiricism." Work in the laboratory was thus a brains-on, hands-on, minds-on activity whose meaning emerged in problem-solving probes. I have described curriculum and instruction encompassing these activities (1955/1981, and, with Watson & Blackwood, 1958). See also Beveridge (1957), Grobman (1969), and Novak (1989). In addition, I have observed such concept seeking and forming and problem finding and probing in the classrooms and laboratories of 82 teachers practicing inquiry teaching (1955/1981).

Dry Run at George Washington High School

The program we built in the late 1930s at George Washington High began with an introduction to a curriculum in biology, which used high school and college textbooks and journals and which was equal to Advanced Placement courses. The class was an invitation to those inclined to the heuristic mode who wished to test their skill in individual or team research on the high school level. Participation was not required nor were there any penalties for those who, for one reason or another, withdrew from the research program. (The school offered a rich program of general education in science and other curricular areas.) A student could begin an experiment, drop out for a period, and return to it after contemplation—with or without commitment to an originative inquiry. This feature of both experimental programs parallels the approach defined by Renzulli and his colleagues as the revolving door model (1981). Under these conditions, with appropriate guidance, certain students undertook originative inquiries, thereby often identifying their own talent. The George Washington procedure validates the oft-repeated findings of research that, given the opportunity, students can judge their ability to undertake an opportunity for special achievement by examining their own purposes and past accomplishments. Through self-selection and self-identification, students with access to equal opportunity actively sought differentiated study environments. Thus, they aimed to fulfill their powers in the pursuit of personal excellence.

The selection of students was *not* based on a predetermined level of IQ, or a prepared entrance examination. Our interviews showed that both young and parents—and the importance of parents in the ecology of achievement cannot be overemphasized—were prepared to accept a self-imposed opportunity for identification of promise through work, just as prospective players try out for an athletic team or musicians audition to join an orchestra. Our practice gave *all* our students access to equal opportunity, while making available self-selected directions for their varied capacities, ambitions, and destinations. Thus, we as teachers fulfilled *our* obligation to serve the needs of a heterogeneous population.

Originative Inquiry: Precursor to Intereffective Teaching and Learning

In such programs as that conceived at George Washington High and maturing at Forest Hills High, the young undertook research-productive, originative inquiry resulting in new knowledge, testable and falsifiable by the template of processes and procedures of mature scientists. Their achievements, written with the signature of the scientist-to-be, reflect the philosophy, the observable behavior, and the methodology of science.

The Student

The teaching and learning of the modes of the scientific approach through idea-enactive, inquiry-oriented investigation and research-productive behaviors have been the subject of substantial research. See my studies in 1955/1981, 1958 (with Watson and Blackwood), 1962, and 1979, as well as that by Bruner (1966). Renzulli's (1981) revolving door identification model similarly provides a practical plan for developing a talent pool. Sternberg (1981, 1985) also illuminates an understanding of behaviors in originative inquiry with his eclectic theory of intelligence and conceptualization of cognitive play. (See Shiffrin & Schneider, 1977.)

A centrality in the singular self-construct of the student engaged in scientific inquiry has pertinence here. Theirs is the habit, perhaps the "character-rooted passion" (Fromm's 1959 phrase) of seekers in perpetual acts of scholarship, not summarized in the school's course of study but devoted to a life-long curriculum. Their work embodies the vocation of study and contemplation. Gladly and boldly, self-imposed by rigorous habit, their regimen exceeds the demands of schooling and even of the university. Their self-construct (the building of self-concept) expressed in original work is a criterion sample (McClelland, 1973; Tannenbaum, 1983; Wallach, 1976). It is sharply distinguished from the cursory identification of giftedness or talent in the young through IQ scores or other tests of ability and/or achievement.

Certain curricular aspects of originative inquiry are based on a matrix of massive, structurally organized knowledge (Gagné, 1965). Thus, students participating in both the dry run at George Washington and the full program at Forest Hills in the 1940s and 1950s, worked first with beginning high school textbooks, which were superseded by college texts. They also had access to a decent school library, area libraries, and college collections. In the later stages of the program, they also had a hand in planning the course of study, taking responsibility in individual or group "independent study" for work that would not be part of classroom instruction. The work they chose was steeped in idea-enactive, inquiry-oriented, research-productive instruction. All had formally planned to enter college, and 96 percent did so immediately after graduation from Forest Hills.

Problem Seeking and Finding

Through wide reading and independent study, about 50 percent of the students focused their interest in a particular field. About 15 percent came from professional families; their parents' careers were in areas such as medicine, engineering, and science. Their fields of interest were often influenced by their home environment. Students at Forest Hills had access to the school faculty's colleagues in the colleges and universities of New York City and environs; the professors were usually eager to enter our consultants' arena—as were two psychologists. Several of us at Forest Hills had been gathering studies from which problems might be derived. Thus, no student who wished to undertake inquiry was without background information that might lead to originative work; however, 62 percent came to us mentors to discuss a defined problem (the solution of which was necessarily adaptable to equipment available in the school, a nearby cooperating college, or an industrial research center). In the main, the student invented his/her equipment, modified what was available, or worked in a nearby laboratory. In all cases, the scientists-to-be worked with full knowledge and permission of their parents and school counselors.

Critical Thinking

The plan, execution, and completion of an experiment is in itself a test both of critical thinking and of the processes that brought the work into existence. Only through the clearly and definitively explicated protocol is the experiment replicable; and the explanations of the results (inferences and conclusions) testable. The works coming out of originative inquiry (the center of the experimental approach) are thus data from which the thoughtfulness that created the experiment clarifies and makes concrete the students' critical thinking.

The Teacher

I made 22 detailed case studies from a sample of 82 teachers of the science talented described in teaching practice within class and laboratory instruction (1955/1981). After finishing that study, I had the opportunity to observe 48 more. I noted that teachers who utilized the research-productive mode of teaching were both innovative themselves and open to new approaches suggested elsewhere. Sternberg's (1981) felicitous concepts characterize these teachers. They were, for instance, highly experienced in inquiry, "nonentrenched" and insightful in relationships with their pupils, and had "automatized" processes, as they proceeded with their research. These teachers, who were also effective in guiding students' early efforts to fix on a problem and in their mentoring during investigations, were acting in the mode of graduate advisors serving doctoral students at work on research projects (Renzulli, Reis, & Smith, 1981).

The mutual relationships of teacher and student in the close-bound intereffectiveness of group instruction in class and individual instruction in research were forged in a close bonding—a charismatic relationship. Agreement and disagreement in the relationships of the young and their mentors were expressed in easy and warm trust. The bond was forged in the search for new knowledge in the comfort of Bronowski's dictum, an adage: "We *ought* to act in such a way that what *is* true can be verified to be so" (1956, p. 74).

> ***First***, these teachers had learned how to do what they asked of their students; next, they actually *did* what was necessary to evoke their students' behaviors of inquiry. The 22 with research experience brought to our discussions methodologies of experimental technique gleaned from a host of sources. They were, in addition, excellent technicians, quick in devising equipment to fit an experimental design. They united the young and their discipline in a respect for learning. Their idea-enactive, inquiry-oriented, research-productive teaching was grounded in respect as well for the "contrary imaginations" (p. 92) that question easy assertions.
> ***Second***, such teachers emphasized the continuum of experience and pressed a developmental point of view in the uses of intelligence by tying the young to past experience in the modes of research—particularly in relation to the teachers' own adventures in problem solving.
> ***Third***, by "getting out of the way" (Roe's phrase, 1953) of the students, these teachers permitted the young free engagement in adaptation, selection, and shaping of their behaviors in real-world experience. Thus, the students could build their own self-concepts and configure their own methods of approach to a problem. (The teacher-mentors were almost always on hand to listen and, almost always by questioning, at times to redirect attention.) Together teachers and students constructed a learning environment of mutual constructive affection, which, to quote Einstein again, encouraged "experience in search of meaning."

These teachers' intellective approaches express aspects of Sternberg's subtheories within the triarchic theory of intelligence (1985). However, equipping teachers and students prior to the experience of teaching and learning is for naught if they are unsupported by the environment in which they find themselves. Teacher and student are two parts of Renzulli's paradigm (1992). His third part, curriculum, energizes the idea-enactive, inquiry-oriented guided learning that ought to be central to students' environment. Thus, an effective curriculum, supported with adequate resources, equipment, and constructive practice, needs to be flexible and innovative. If the ecosystems in which they exist are friendly, students, teachers, and curriculum can and do step out of tradition and transcend the familiar paradigm of teacher and class.

The Ecologies of Achievement

The family-school-community, cultural, and college-university ecosystems described earlier interpenetrate and can become emblematic of ecological mutualism. Certain partnerships of school, corporations, and university personnel have already shown their power to sustain human potential. One thinks, for instance, of the work of the "I Have a Dream" program begun by New York entrepreneur Eugene M. Lang, who in 1981 adopted a class of sixth graders from East Harlem Public School 121 and promised each one who graduated from high school a college education. Ninety percent of them graduated from high school, and 60 percent went on to college. As of 1994, there were over 150 "I Have a Dream" chapters in 57 cities serving 12,000 children. The Walter

Annenberg Foundation grants, which provide opportunities for teachers nationwide to learn about good math and science teaching, marshal support for reform among parents and administrators, and work to include underrerepresented populations, form another effectively functioning ecosystem. Joint activities in support of teaching and learning can be extremely powerful. In paradigm, student, teacher, and supporting ecology are part of a whole—and the whole is larger than its parts.

Renzulli (1992) creates a whole in his quest for a paradigm-shift in instruction and Sternberg (1985), another, in his architecture of intelligence. The scientist-to-be can emerge through use of certain processes and procedures of the mature scientist's methods of intelligence.

A Paradigm: In Sum

In a paradigm evoking science talent, the three intereffective elements—students, teachers, and the other individuals and entities composing the ecologies of achievement—support curricular and instructional methodologies that make possible self-selection and identification through the methods of originative inquiry. These elements cannot be considered apart: They are an inseparable, entwined, connected, and intereffective whole. The paradigm then describes the "methods of intelligence" (Bridgman's phrase, 1945) within the "human ecological structure" (Tannenbaum's phrase, 1983). The behaviors of the scientist-to-be emerge in certain processes and procedures demanded by the constructivist experimental mode of originative inquiry and suffused by the processes of critical thinking.

Behaviors Preceding Early Expression of Science Talent

Approaches in Originative Inquiry

At Forest Hills between 1944 and 1954, the senior mentors observed 354 students involved in the "arts of investigation" (Beveridge's phrase, 1957), studying closely 62 of 164 students who completed inquiries. The 62 freely discussed their probes, including their problem finding, their concept seeking and forming, their difficulties, and their "Eurekas!" From the papers they submitted to the Science Talent Search and their candid remarks, we confirmed our insights into the inquiry modes of the apprentice scientist. The problem-solving processes emerging in conferences with mentors and in seminars, as the students explained what they did and why, came from wondrous, idiosyncratic, inventive personalities, steeped in "contrary imaginations." Their processes of inquiry, including metacognition, flashes of insight, leaps of intuition, and careful reporting, formed a happy tumult.

From the comments of a variety of observers in our classrooms (scientists, psychologists, teachers from other schools) and from my observations, I was able to organize these behaviors into skeins within the mêlée. What emerged is something approaching a composite portrait of science talented youths in acts of experimental inquiry.

Behaviors in Originative Research—In Reality

A beginner in science finds and is intrigued by a problem unearthed in a personal probe in reading or other experience or accepts an original problem from a mentor in school or in a neighboring college or laboratory. Then, s/he plans the protocol of an experiment and devises a working hypothesis to undergird the plan for subsequent work. Next, s/he prepares a schedule of inquiry into the literature and sorts out the significant judgments, old and new.

Although such consultation may already have taken place, at about this time s/he meets with a mentor to find a scientist in the field willing to advise in writing or in person. With the help of this mentor or his/her original advisor, s/he decides, after trials in the laboratory, whether initial probes support the tentative hypothesis. In conciliating sometimes opposite paths of inquiry, s/he discards the first attempt and successive others for models with a better fit and revises the hypothesis. Satisfied finally, the student attempts to defeat it with carefully devised experiments with more adequate controls and repeats the experiments in the to-and-fro required for careful thought and increasingly accurate measurements.

Now, s/he speculates anew, often joyfully, as the findings confirm the hypothesis but nevertheless seeks to reconcile doubts and, in an attempt to reconcile opposites, consults with a mentor. Now, s/he fashions a tentative conclusion and explanation but continues to withhold judgment on its validity. Conducting a review of the evidence, s/he questions again the discovery and its possible utility; finally, confident of the work to the extent of a willingness to share the new knowledge gained, s/he writes a full protocol, revises it for clarity of explanation, and thus engages in the final test—confirmation and critique—not only from peers but from the scientist-mentor in the field.

All this happens in intereffective feedback in a cycle of contemplation and understanding, in sudden bursts of insight, and in intuitive leaps beyond the information known in the mêlée and flurry of ardent inquiry, as s/he reaches a conclusion, sometimes magnificently wrong but as often, as I have showed, triumphantly right (1992).[20] The turmoil of the discovery processes is, perhaps, even greater in adolescent inquirers than in mature researchers, when the physiological upheaval the young are necessarily undergoing is compounded by their intellectual excitement.

Almost *never,* in my personal work with some 26 scientists prior to teaching, with 14 more during the Sputnik crisis, and with the 354 young doing originative exploration between 1944 and 1954, did I note their paths following the procession of steps of the so-called "scientific method." On the other hand, often with Bruner's "effective surprise" (1979), I saw brilliant mental breakthroughs—evidence of methods of intelligence beyond the capacity of published tests of creativity. Bridgman made this point decades ago when he wrote that the scientist, in attacking a specific problem, suffers no inhibitions or precedent on authority but "is free to adopt any course that his ingenuity is capable of suggesting to him . . . In short, science is what scientists do, and there are as many scientific methods, as there are individual scientists" (1949, p. 12). In teaching and learning, students may see the limitations of the "empirical approach" (Conant, 1952),

But scientists seem to value knowing what's wrong as much as what's right: both spur them on.

[20]Thanks to John Wiley and Sons (New York) for permission to use a modification of ideas presented in my April, 1992, essay, "Science talent: The play of exemplar and paradigm in the science education of science-prone young," published in *Science Education, 76*(6), 121-139.

The Familiar Steps of the "Scientific Method"—In Myth

In schooling, the scientific method "describing" the process by which scientists work is generally deduced from studies of the *finished* reports of scientists to colleagues in their particular community. Day (1989) describes the structure of such papers as comprising *I*ntroduction, *M*ethod, *R*esults, *a*nd *D*iscussion (acronym *IMRAD)* (p. 335). This strikes me as a useful description of many published papers. It does *not,* however, describe the intereffective action of thoughts—seemingly springing from nowhere, affecting the action of assemblies of neurons, causing flows of physicochemical excitants in ways not yet fully known that reach other synapses, and leading to what we call thought and sometimes action. Inquiry as style is not a rote of discovery but a veritable breakthrough in a particular originative behavior.

Here, I am discussing not only the originative work attested by the scrutiny of representatives of the community of scientists in the Science Talent Search but also the work of practicing researchers. At times, of course, there is the chance discovery. For example, when a young investigator found in cereal a *Tribolium* beetle with eight legs (instead of the six usual with insects), he interrupted his planned investigation for a new more interesting problem.

He set the old inquiry aside and brought the new one to a surprising solution. When he thought that solving the problem was within the range of possibility, disappointing negative results appeared. Still, they could be equably verified, and they pointed to an interesting new question. Another adolescent theoretician never quite finished her attempt to develop a "scientific-mathematical model of waste disposal without environmental hazard." She did, however, go on to advanced university studies in ecology and environmental sciences.

Ordering Originative Inquiry Into Steps

The behaviors noted above *could* be observed and ordered into an organized description of procedures that fall under Bruner's psychomotor, symbolic, enactive, and iconic modes of behavior (1979). What happened, however, during the students'—like the scientists'—brains-on, minds-on, hands-on activity was *not* well-ordered during the mêlée of inquiry. Nonetheless, the *results* could be described in writing as part of a "well-ordered empiricism" (Conant, 1952), if the investigators were to report their findings to others (Day, 1989). Thus, to create from their turmoil a straightforward catalog of events, one could say the students were able to

- note discrepant events
- uncover a problem situation within the event they wanted to investigate through discussion and independent study
- uncover the prior literature related to the work on the problem
- propose a hypothesis and gather the equipment and materials to carry it forward
- design an investigation involving observation and experiment on the basis of the hypothesis
- record their data (including error)
- design control experiments in an attempt to defeat their hypothesis
- offer a tentative solution, to be conciliated with later ones
- propose new experiments in an attempt to defeat their solution
- state their solution in a systematic assertion
- present their work in seminars with other apprentice-scientist young

- write up and deliver their assertions and predictions in a paper to their peers in a science congress
- offer their work for critique to their mentors—scientists in the field
- enter their work in the Science Talent Search for further appraisal by a panel of scientists in the various fields

The list above of planned research steps *does not* describe the mêlée recounted earlier. It does not even describe cognition, much less the affective and nonintellective factors such as persistence. It *does* describe an imagined stately procession of the arts of inquiry, a path appearing to lead straight to IMRAD.

In spite of the apparent disorder of their method of knowing, a state reflective of that of many mature scientists, acquisition of knowledge came almost as second nature to these students. Recall their wide use of available written resources and the part some of them took in planning their own course of study. They were scholars in name, deed, and fact.

Originative Inquiry as Test

The teacher-mentors at Forest Hills had been unfavorably impressed by the tests of scientific creativity at hand. We tended sharply to the conclusion, later expressed in Wallach's researches (1976), that "tests tell us little about talent." Thus, we saw the paradigm of the experiment, undertaken within the context of scientific research practiced and resulting in an originative *work*, as an adequate test of talent in science in the young. This process, of course, parallels the observable modes of scientists. In this view (sustained in the literature), if a work requires an intensive use of the methods of intelligence, use of IQ as a prior measure of selection was neither necessary nor sufficient.

In fact, consulting psychologists studying IQ measures taken after the completion of the inquiry showed that the students' respectably high scores were not sufficient to begin to predict their high-caliber invention, their brilliance in inquiry, and their sustained persistence in spite of obstacles and "failure" of hypotheses. On the contrary, my 10-year study found that almost one-half of the 354 students in the inquiry-centered classroom, who had IQs of comparable levels of the persisters, either did not undertake originative work, or, having begun it, did not finish (1955/1981).

Originative inquiry appears to probe elements of intellective behaviors not embraced in IQ testing. The different styles of inquiry require the intereffective play not only of the substance of science but also of the subtle intellective and nonintellective factors (MacKinnon, 1962; Tannenbaum, 1983). Success in originative inquiry requires a facile, even executive, ability to manage oneself in relation to favorable or unfavorable environmental factors. For example, students chose whether to submit their papers to the Westinghouse Talent Search or not; they made other significant choices as well.

All the papers submitted to the Search were (and are) refereed by a panel of scientists, psychologists, and educators. A project approved by the working scientists was considered to be empirical evidence of the presence of science talent and a high level of achievement and creativity (Edgerton & Britt, 1943, 1944; Phares, 1990).

Procedures Stemming From Critical Thinking

The plan, execution, and completion of an experiment is in itself a test of critical thinking through a work and the processes and procedures that brought it into existence. Only through the protocol of the experiment clearly and definitively explicated in publication, however, is the work replicable. Thus, the explanations of the results (the inferences and conclusions) are testable. Further, the explanations either fit (or they do not) into a hypothesis or theoretical-conceptual model—either way increasing the burden on critical thinking. The ensuing argument often rests in both epistemic and empiric schema. The works coming out of originative inquiry are thus data from which the thoughtfulness that created the experiment emerges in the thinking basic to its acceptance by the community of scientists. What follows, then, are still other aspects of critical thinking—pro and con—in both dialogues (in which other scientists take the place of the experimenter to determine his/her point of view) and dialectical modes (in which opposites are reconciled). Through either process, a new problem may emerge or another hypothesis.

The young at Forest Hills who presented their experiments in scheduled seminars faced penetrating questions not only from the apprentice scientists and their teacher-mentors, but also at times from visitors from nearby colleges and universities. These seminars evoked critical examination of problems, hypotheses, processes, and led to next steps. And finally, if the young experimenters wished to present their papers to the Science Talent Search, panels of practicing scientists probed their defenses of processes, of explanations, of—in fact—the caliber of their thinking. Their papers were at times published by the Science Talent Search, which often followed-up with reports on the careers they eventually chose after winning the competition.

The critical thinking processes witnessed in originative inquiry are often parallel to many aspects of the models of Bloom's (1956) hierarchy of thinking skills; Costa's (1985) description of critical thinking skills in curriculum, instruction, and the classroom; Renzulli's (1977) triad; Sternberg's (1985) triarchic theory of intelligence; and Walters and Gardner's (1986) logical-mathematical intelligence. Gubbins' *Matrix of Thinking Skills* (1985) offers a thorough and comprehensive review and analysis of major values and processes in thought and thinking by these and many other philosophers, social scientists, and educators, as well as a number of tests of cognition. I have found Gubbins' *Matrix* a useful measure of the critical thinking skills and values of science talented students.

The observations my colleagues and I made of the behaviors of the young in originative inquiry, the agreement of the teacher-mentors in a critique, our own described categories of critical thinking, as well as the evaluations by visiting scientists, all confirm that doing originative inquiry can reveal elements of critical thinking requisite to scientific problem solving.

Our preference for originative inquiry as a test of promising talent is seconded by the judgment of a considerable number of scientists on the panels of the Science Talent Search. The validity of the process is also documented by the fact that many of the winners and runners up became scientists solid in their contributions. (See Table 2.)

I posit that the originative-inquiry exemplar is actually more useful in the assessment of skill in science than tests of critical thinking (see, for example, Sternberg, 1985). A combination of the two approaches would probably be most effective of all.

Table 2

Profiles of Search Winners, 1942-1980[1]

Degrees Earned:	B.S. or higher	99 percent
	Ph.D. or M.D.	70 percent
Present Employment:	College or University	43 percent
	Industry	25 percent
	Medicine	12 percent
	Government	7 percent
	Other (nonscience)	7 percent
	Other (science-related)	6 percent
	Awards of Search Winners, 1942-1994[2]	
Awards:	Nobel Prizes	5
	Fields Medals (the highest mathematics honor)	2
	MacArthur Foundation Awards	9
	Medal of Science	2
	Albert Lasker Basic Medical Research Award	2
	National Academy of Sciences	30
	National Academy of Engineering	3
	Sloan Research Fellows	56

1 Data from Science Talent Search finalists after 38 years of the competitions, when Science Service reached 930 of its 1,431 winners by questionnaire.

2 Data from Phares (1990, pp. 80-82), updated by Westinghouse.

Critical Thinking in Originative Inquiry

Noting the obvious relationships among hands-on, brains-on, minds-on activity in the problem *doing* that often precedes genuine problem *solving*, some see *the* clue to stimulating inquiry as being rooted in instruction beginning with hands-on activity as stimulus. Others, such as Gagné (1965), Golovin (1963), and many of the contributors to Taylor and Barron (1963), suggest that masses of structurally organized knowledge are necessary to stimulate problem *solving*. As noted earlier, there are alternative hypotheses to the procedure of originative inquiry as a measure of science talent (Lynch, 1990).

As in many crises, a panacea has emerged. While "hands-on" activities may seem an appropriate reaction against excessive dependence on lecture and text, and while Daston may be right that "world views begin with in-the-fingers knowledge" (1989, p. 361), she would be the first to admit that they don't end there. Hands-on experiences may in general trigger processes of imagination better than lecture; however, relying *only* on "hands on" is crippling to the science prone. (See also Khatena, 1969, 1982; Khatena & Torrance, 1973.)

While my observations are not sufficient to make a case for the ability to imagine without concrete props as essential to the process of inquiry, over half (218) of the 354 students reported that they "saw" the equipment planned or invented for use in their experiments; they even imagined the sequence of their experiments during inquiry. They seemed to equate "thinking" with a kind of "imaging." Physiologically, an "image" fires up other neurons by racing across synapses and thus raises a chain of intereffecting visual images (ideas), which result in a further chain of reasoning, effecting further inquiry.

Of 61 scientists in Roe's study (1953), 55 percent of the biologists and 78 percent of the physicists utilized "concrete three-dimensional and other modes of verbalized and symbolized imaging" (p. 147). At this writing, however, we do not have a clear notion how physicochemical activity in a neuron forms a thought, nor how brain forms mind; the latter, in turn, depends on the intereffective exchange of mind with other minds.

Originative Inquiry as an Index of Science Talent: Focus on the Westinghouse Science Talent Search

The development of the Westinghouse Science Talent Search in 1941, which one of its winners Nobelist Glashow calls "the science fair of all science fairs," (Phares, 1990, p. 16) brought to the fore the possibility of a predictive real-life test of science talent for America's young. Sherburne, then the director of Science Service, put the aim of the Westinghouse Science Talent Search thus: "The evaluation is on the basis of the student's ability to 'do' science in a way that is analogous, though at a less sophisticated level, to what a professional scientist does" (personal communication, 1987). Seaborg, Nobel Laureate, educator, chairman of the Science Service Trustees, and since 1963 a Science Talent Search judge, explains: "We are looking for the person's potential as a scientist. I look for the ability to think; a certain minimal amount of knowledge, of course, but more important, creativity, if I can discern it" (Phares, 1990, p. 54).

VanTassel-Baska (1984) pointed out that "the Talent Search focuses much more sharply than most identification protocols on self-election or the volunteerism principle. The commitment to the Talent Search and to follow-up procedures must be made by students and parents in order for the identification to occur" (p. 175). Former Principal of Bronx Science, Kopelman, explaining why—of all the awards his students won—he announced only the Westinghouse, said, "A young person has to involve himself for a prolonged period in a piece of work and then do a *research paper* on it. Then the work is judged by *research people*. That's very special" (Phares, 1990, p. 53).

Wondering "What will be the most fruitful approaches for research on giftedness in the next 5 to 10 years?" Siegler and Kotovsky (1986) suggest that

> One useful approach would be to focus on people in the process of becoming productive—creative contributors to a field, for example, high school students who win Westinghouse Science Competition prizes . . . . They already have made creative contributions—they have not just learned to perform well on tests—but they are still in the process of becoming eminent. (p. 434)

In 1954, Michael Fried submitted a paper to me at Forest Hills on "An Ultraviolet Photosensitization in Para-Aminobenzoic Acid and Pantothenic Acid Fed to *Tribolium confusum*." His work earned him a place as a finalist in the Science Talent Search. Even without access to computers, about 95 percent of the 354 high school students who undertook the science talent study program over the 10-year study worked on credible, often ingenious, projects (Brandwein, 1951; Zim, 1940). An examination of the titles of several papers among the 40 submitted by the finalists some five decades later indicates that winning Search papers seem more often to depend on sophisticated technology than the projects typical in the 1940s and 1950s. For example:

- Defining the Molecular Characterization of the p70 Autoepitopes—Tsz Wang Ng, 17, Midwood High School, Brooklyn.
- Discovery and Characterization of a Gene Essential for Nitrogen Fixation in the *Cyanobacterium anabaena* spp. PCC 7120—Matthew Peter Headrich, 16, University of Chicago Laboratory Schools High School.
- Acetone Metabolism by Cytochrome P450IIEI: Novel Pathways of Glucose Formation From Acetone in Humans—Peter Yee Cheung Ho, 17, Bronx High School of Science, New York.
- Functional Response of *Zeteticontus utilis* to Varying Densities of *Carpophilus humeralis*—Ryan Mamoru Iwaska, 17, Henry Perrine Baldwin High School, Wailuku, Hawaii.
- Optimizing Rotational Gel Electrophoretic Separations of DNA—Jennifer Lynn Ryder, 17, Edison High School, Fresno, California.
- Reaction of Various Derivatives of N-methylpyrazinium Iodide with Pentacyano (dimethysulfoxide) ferrate (II) as a Way to Determine the Structure of These Derivatives—Mina Kim Yu, 17, Thomas Jefferson High School for Science and Technology, Alexandria, Virginia.
- Expression of Class II Molecules in B-Cell Hybridomas: Transfection by Electroporation—David Michael Shull, 17, Henry Foss High School, Tacoma, Washington.

By the 1990s, the Science Talent Search had spread from the earlier concentration in the Eastern states with the majority in the Northeast to a broader representation of schools in many states and dependencies. The seven selected above from the finalists in a recent Search indicate the geographic spread.

Two Ecologies of Achievement: Select Science and Heterogeneous Schools

The special science schools, with their students selected for entry by examination, and heterogeneous schools, with differentiated programs within a curriculum open to their residential populations, did about equally well until the late 1980s in producing Search winners and runners up. (See Tables 3 and 4, Stanley (1987, 1991) and Lynch (1990, 1992) on science high schools, and Linder's (1987) response on the necessity that heterogeneous schools institute differentiated programs to meet the needs of their students.)

Table 3 lists winners by school 1942-1994; the order of the listing is significant in the relative stability over nearly half a century of the ecologies of achievement in certain schools. Table 4 tallies finalists by communities within New York City. Table 5 (1944-1954) compares the Science Talent Search results of two select science high schools (Stuyvesant and Bronx Science) and one heterogeneous school with a program in originative inquiry (Forest Hills); in that decade each school produced 17 Search finalists.

Table 3

Westinghouse Science Talent Search: 1942-1994[1]

School	Location	Winners
Bronx High School of Science[2]	New York, NY	123
Stuyvesant High School[2]	New York, NY	83
Forest Hills High School	Forest Hills, NY	42
Erasmus Hall High School	Brooklyn, NY	31
Evanston Township High School	Evanston, IL	29
Benjamin Cardozo High School	Bayside, NY	26
Midwood High School	Brooklyn, NY	27
Jamaica High School	Jamaica, NY	19
Martin Van Buren High School	Queens Village, NY	16
Brooklyn Technical High School[3]	Brooklyn, NY	14
Phillips Exeter Academy	Exeter, NH	12
Central High School	Philadelphia, PA	11
Abraham Lincoln High School	Brooklyn, NY	11
Hunter College High School	New York, NY	11
Lyons Township High School	La Grange, IL	9
New Rochelle High School	New Rochelle, NY	9
Coral Gables Senior High School	Coral Gables, FL	9
North Phoenix High School	Phoenix, AZ	9
Montgomery Blair High School	Bethesda, MD	9
Melbourne High School	Melbourne, FL	9
James Madison Memorial High School	Madison, WI	9
Ramaz High School	New York, NY	8
Thomas Jefferson High School for Science and Technology[2]	Alexandria, VA	8
Newton High School	Newtonville, MA	7
Niles Township High School	West Skokie, IL	7
Columbus High School	Marshfield, WI	7
Stephen Austin High School	Austin, TX	7
Alhambra High School	Alhambra, CA	7
Ward Melville High School	Setauket, NY	6
La Jolla High School	San Diego, CA	6
Woodrow Wilson High School	Washington, DC	6
Wakefield High School	Arlington, VA	6
Princeton High School	Princeton, NJ	6
Nova High School	Fort Lauderdale, FL	6
McLean High School	McLean, VA	6
Eugene High School	Eugene, OR	6
Townsend Harris High School	Flushing, NY	6

[1]Table based on data provided by Dorothy Schriver and Carol Luszcz and updated by Pamela Weddle and Karen A. Royden (Science Service, Washington, DC). (Schools listed have produced six winners and more.)

[2]Selective science high school. From 1942-1988, about the same number of Science Search finalists came from specialized science schools and general high schools. After 1988, the specialized schools produced many more winners than heterogeneous schools. A study of the factors influencing this change would be most useful.

[3]School combines a science curriculum with one in technical engineering.

Table 4

Science Talent Search Finalists: Science Schools and General Schools by Communities, 1942-1988

Borough	Public Schools	Finalists	Total for Boroughs
Bronx	Bronx High School of Science	106	106
Manhattan	Stuyvesant High School	63	63
	Total Special Science Schools		**169**
Brooklyn	Abraham Lincoln High School	11	
	Erasmus Hall High School	31	
	Midwood High School	20	62
Queens	Benjamin Cardozo High School[1]	25	
	Forest Hills High School	42	
	Jamaica High School	19	
	Martin Van Buren High School	15	101
	Total General Schools		**163**

[1]Benjamin Cardozo High School—late entry (1967).

Thus, between 1942 and 1988, within the area of New York City, the two science schools garnered a total of 169 finalists. Seven neighborhood schools, accepting the heterogeneous population of their communities and offering differentiated programs for their smaller cohorts of science prone students electing to undertake originative inquiry, produced 163 finalists.

Table 5

Science Talent Search Finalists and Runners-Up: Westinghouse Data, 1944-1954

School	Finalists	Honorable Mention
Bronx High School of Science[1]	17	79
Stuyvesant High School[1]	17	53
Forest Hills High School	17	57
Midwood High School	8	34
Abraham Lincoln High School	8	19
Evanston Township High School	8	incomplete

[1]Selective science high school.

The numbers of Science Talent Search winners coming out of these different kinds of schools stay close to each other both across the decades (Table 4) and within the first 10 years of the Search's creation (Table 5). While the means of selection of their populations differs enormously, somehow they must both be creating ecologies of achievement.

Inferences

The Science Talent Search, which is based on an originative inquiry resulting in a work, may be considered a valid test of adolescents' expression of science talent.

Select science schools, particularly instituted to carry on enriched and accelerated programs for the gifted, offer differentiated advanced programs in science and mathematics within a full enriched college-preparatory program; they also furnish models of programs in originative inquiry.

Similarly, schools with heterogeneous populations from their surrounding neighborhoods and committed to programs of general education can and do invent differentiated, enriched programs in curriculum and instruction to give students opportunity to carry on originative inquiry. Thus, they provide models of differentiated courses for other general nonspecialized schools.

In short, select science schools and heterogeneous schools constitute different ecologies of achievement, both capable of encouraging significant originative work in science.

It is probable that select science schools may offer the initial model or paradigm of originative inquiry that stimulates the invention of other models within the programs of general education in heterogeneous schools. The paradigm of originative inquiry is a way of identifying promise in students who might tend in the future to choose a career in science. As such, it deserves a firm place in differentiated curriculums in science.

For Further Inquiry

Does a test of ability in originative inquiry probe elements of intellection not embraced in IQ tests?

Do the procedures demanded by originative inquiry described here and in other studies encompass the various categories of critical thinking skills?

Can a work coming out of originative inquiry define a unity of supporting intellective, nonintellective, and facilitating environments characteristic of a desirable ecology of achievement?

Is it conceivable that an originative work be a test of science talent?

The invention of a modern program of general and special education is among all nations' major priorities, because of the need for a thoroughly schooled and educated citizenry as well as for programs of benefit to its citizens. Are not, therefore, differentiated programs enabling gifted and talented students to fulfill their worth as citizens and as contributors to society necessities rather than options?

Should not all approaches to encourage science talent mirror the epistemic and empiric portrait of science inquiry and its critical thinking, as well as the acquisition of knowledge?

Is it not clear that the time required for originative inquiry is well spent in a high school program in light of the observed commitment and persistence of science talented young, who work hard and effectively on their total curriculums as well as their inquiries?

Some Assumptions

A model in education is designed to further decisions advancing teaching and learning. In planning further inquiry, theoretical constructs turn out to be most practical: They are rich in hypotheses, with designs for self-testing, and, thus, they reach for foresight and understanding.

My direct observation of the behaviors of the young undertaking originative inquiry in the environments of teaching and learning led me to discard the Cartesian concept of one-to-one correspondence of cause and effect and to develop a triad as a working hypothesis:

> *High-level ability in science is based on the interaction of several factors—genetic, predisposing, and activating. All factors are generally necessary to the development of high-level ability in science; no one of the factors is sufficient in itself. (1955/1981, p. 12)*

While I stand by this hypothesis, I am pleased to make modifications in the considerable light shed by studies now available.

Relevance to Present Studies

My commitment to originative work as an essential index of science talent accords with Renzulli's (1992) subtriad of input, process, and *product*. My conviction also complements Sternberg's (1985) call for real-world tests of intelligence.

My point that science talent is indicated and supported when the young select themselves to undertake a demanding study and long-term originative inquiry (and persist, as 75 percent of the entry group did, to sustain it) is parallel to Sternberg's assertion that behavior is intelligent to the extent that it is used to adapt or shape the environment. These young undertook and adapted the "automatized" and "nonentrenched" behaviors necessary to undertake and complete a novel task of originative inquiry.

In reflecting on the nature of science talent or on giftedness in general, one is inclined to question how far the intellective factors in the present study on science talent are constrained by the nonintellective ones. MacKinnon (1962) wrote that "our data suggest, rather, that if a person has the minimum of intelligence required for mastery of a field of knowledge, whether he performs creatively or banally in that field will be crucially determined by nonintellective factors" (p. 493).

My study seems as well to second Tannenbaum's (1983) facilitators in the intereffective play of the general ability (the "g" factor—as a concept, not an empirically defined entity) with its sliding scale in all high-level talent areas. Tannenbaum writes of the special ability apparent in particular aptitudes, such as outstanding performance in originative inquiry; of nonintellective factors, such as ego-strength, dedication, and will; of environmental factors, such as a stimulating home, school, and community; and of chance—the unpredictable events in a person's life—including luck (pp. 87-89).

Originative inquiry calls on *general* and *special* abilities. One of the nonintellective factors is persistence, which Roe (1953) noted in selected working scientists and I (1955/1981), in the young. Tannenbaum pointed particularly to dedication and will. Environmental factors are also important, including, of course, the chance to attend a school whose opportunities included originative inquiry.

If the evidence here supports the studies of Renzulli and Sternberg, both asking for reality-based intelligence tests, as well as Tannenbaum's psychosocial theory, then producing a work through originative inquiry may well measure science talent. Perhaps this finding has broader applications. Perhaps the procedures of originative research by adolescents could also measure talent in other domain-specific fields open to originative inquiry.

If the opportunity doesn't come in high school, certain evidence suggests that the undergraduate years may not be too late to awaken science proneness, which may bloom to talent. Writes Colwell,

> One characteristic of a significant number of winners of the Nobel prize and winners of other prestigious awards in science and engineering is exposure to laboratory research as an undergraduate—that is, having the opportunity to work in the laboratory with a faculty member on a research project while an undergraduate student. . . . It can be concluded that hands-on experience in the laboratory can be a key factor in the decision of a student to pursue a career in science and engineering. (1992, p. 210)

The National Science Foundation has reemphasized such undergraduate research opportunities and provided funds for undergraduate students to work in research laboratories, and, in 1993, the National Association of Biology Teachers reported on a projected study uniting a high school teacher and a university scientist in developing methodologies for originative inquiry ("New NABT grant," 1992).

The experience of originative research in high school may motivate a decision to pursue a career in science and thus qualify students for continued research in their undergraduate years. Thus, in practice, a science talent expressed early may eventually define itself in a profession that enables one to engage in originative inquiry.

A sustainable paradigm begins to emerge. As it matures in wider usage in the double experience of further discovery and the uses of the discovered, it may furnish a predictable mode of knowing in advance. Originative inquiry can lead to early expression of science talent in the young; it, therefore, is a worthy practice in the quest of the young scientist-to-be fashioning a unique identity.

Construct VI: Within an Ecology of Achievement—A Conception of Science Talent

Bateson's tautology—"What remains true longer does indeed remain true longer than that which does not remain true as long" (1979, p. 228)—is nowhere more appropriate than with regard to the life of a concept. Even when a theory, the apparent terminus of inquiry, converts into another more comprehensive theory, when this resulting skein of numerous acts of discovery becomes a full, satisfying explanation and fits into an inclusive conceptual scheme, the all-encompassing conception nonetheless often remains elusive. Thus, since Copernicus we have moved from an earth-centered to a sun-centered, to a galaxy-centered universe. Then, we have gone beyond into expanding galaxies and into the Einsteinian concept of $E=mc^2$, and then into modes of energy called black holes. Each theory, while at first satisfying as an ending, has turned out to be only the beginning of a series of investigations which led to larger, more encompassing areas for trained intelligence to spawn new investigations.

Science Talent in Practice

Bell meshed present and future, scholars and teachers, in his paradigm of knowledge as "new judgments (research and scholarship) or new presentations of older judgments (textbooks and teaching)" (1973, p. 175). Conant (1947, p. 35) has also seen a continuity in the nexus of new and old judgments with the exploration, explanations, and judgments of scientists. He capsuled scientific foresight and understanding as being embodied in a series of conceptual schemes arising out of experiment and observation and leading to new conceptual schemes. In this way, the cycle of thoughtfulness and contribution in science intermesh.

Bell's and Conant's paradigms (in their contexts) show that new judgments and/or conceptual schemes do not spring Minerva-like out of the brain. Scientists practice an intereffecting collaboration; they are a gathered community, operating in distinctive domain-specific areas, to advance given fields of study. As such, scientists make comprehensive efforts to gain understanding and foresight about the way the world of life, matter, and energy works.

Scientific judgments, concepts, and findings of fact must be testable, and thereby verified, falsified, or amended through commonly accepted processes within a community's structure. Thus, scientists and scholars seek to transmit, correct, conserve, and expand the substance of a field to achieve a continuity of cumulative knowledge. The community is usually tightly knit, given over to a particular subset of a domain (say, astronomy, biophysics, zoology, ecology, organic chemistry, ophthalmology, computer science, psychology, genetics, and the like).

Talent in science is not general. Even in the young, it may be centered in biology, physics, or chemistry, and later it is almost always shown in works undertaken within matrices—often extremely specialized ones—in given fields. Then, as required, the findings are communicated to a body of scientists through specific modes: Say, journals, associations, and meetings. These procedures are self-energizing: The substance in all scientific works coming out of originative inquiry is subject to a well-understood style.

Thus, any findings are subject to the selection and variation of the "discovered and the uses of the discovered" (Whitehead, 1929, p. 25). The facts, hypotheses, laws, theories—any conceptualizations—evolve through continued inquiry into a product, a work. A theory or fact in science, and in any field of scholarship, is subject to test after test as it is used in the continued evolution of a field of study (Ravetz, 1971; Toulmin, 1961).

A Skein of Discovery: Heredity as Exemplar

One of the most striking features of science talent identified in the acts of discovery is the scientist's unrelenting persistence over time. Succeeding generations create their works in part through building on prior findings. Scientists stand *on* the shoulders of others even as they stand shoulder *to* shoulder within the life-sample of a generation of discovery: Examine, for example, the field of heredity.

In a sense, the field was born in the 1660s with Hooke's discovery of cells. In the intervening years, massive searches revealed the network of cellular components of unicellular and multicellular organisms. A century and three-quarters later in the 1830s, Schleiden and Schwann offered their cell theory—cementing prior observations, speculations, and theories. Then, in the next centuries, appeared a torrent of studies—on the architecture of the varieties of cells and their organelles; with descriptions of mitotic division and the equal division of chromatin network; as well as researches into the biochemistry of the cell, singly and within its network of tissues and organs in a variety of organisms. Each work built on prior works and cemented further theories.

In the decade of the 1850s, Mendel did his classic experiments on heredity in garden peas. Twenty years later, Miescher's inquiry into the chemical composition of cell nuclei resulted in a published a description of nucleic acid (a base of present DNA research). In the 1880s, Fleming observed the longitudinal division of chromosomes and implied its relationship with nucleic acid. In the next decades, many researchers including Morgan, Bridges, Sturtevant, and their colleagues developed the chromosome theories of inheritance. In the 1920s, Feulgen and other investigators documented a capstone that coordinated a variety of researches: Two types of nucleic acid (DNA and RNA) exist, side by side, in many cells. This discovery led to the further discovery by Avery and his coworkers in the early 1940s that DNA underlies inheritable functions in certain bacteria. By the late 1940s, persistent inquiry by several investigators indicated that the amount of DNA is constant in a variety of organisms.

In the 1950s, after Watson and Crick proposed a theoretical model of the DNA molecule, Kornberg discovered the replication of DNA and learned that it carries information about inheritable characteristics, that is, the genetic origin of organisms. Now, genetic intervention is beginning to treat some diseases, and Watson heads a team of scientists plotting the human genome. This sequence of discovery—of theories leading to inquiries upon inquiries to further theories and conceptual schemes still incomplete—has spanned centuries. The process continues to move toward a still incomplete conceptual scheme about how specific environments affect the expression of DNA.

The great number of scientists and scholars, acting over many years in a specific field of inquiry, express their various talents differently and are not always fully appreciated. The weight of the history of discovery (or creativity) in various fields, particularly in science, that make society and culture possible is not open to citizens active in the business of life and living. We redact detail, reduce complexity, in order to make sense—to make a certain confidence possible. Thus the culture may, and often does, reify a body of knowledge and inquiry in an eminent person. The impulse is perfectly understandable. But in so doing, the metaphor of "giant" and "dwarf" persists: The maxim, usually attributed to Newton, is that "Even a dwarf can see further if he stands on the shoulders of giants." But here too the work of centuries stands as evidence. As decently translated from the Latin, the idea goes as far back as Lucan (A.D. 30-65). Newton seems to have stood on Burton (1577-1640) who topped Lucan. (For a history of the maxim, see Merton, 1965/1985.)

Thus, the past—in literature, in aphorism, in inquiry (and in its terminus, theory)—changes as it melds with past and present and affects the future. The indexes of modern discovery suggest that, generally, a giant sees further after a number of respectable, hard-working dwarfs produce analysis and inquiry on which s/he can stand. Indeed, Crick responding to the biochemist Stent (1974; in Stent 1989), agreed that "if Watson and Crick had not existed, we would have had the DNA double helix anyway" (p. 107). That is, given the course of scientific discovery, which uses the past to uncover the future, their finding and theory were within the course of steadfast change.

Recognizing Early Expression of Science Talent

The foregoing implies a base for the conception of science talent: It doesn't lie *only* or *mainly* in the fast-paced acquisition of knowledge, however significant as an index of individual intellection. Science talent lies in a combination of knowledge with the capacity to undertake originative inquiry.

The life samples of students doing originative inquiry reflect, as in a mirror, images of scientists working in real-life scientific inquiry. Construct III attempts to describe realistic learning situations and productive and creative approaches that can contribute to originative inquiry expressed by developing science talent.

An Operational Definition of Science Talent

A number of theoreticians call for definition of talent through productive work. For example, Renzulli (1992) urges,

> We need to explore new research paradigms that focus on the intensive study of young people at work in practical and realistic learning situations that place a premium on creative productivity rather than structured lesson learning, regardless of how advanced that learning may be. In this regard, we must learn to view special programs as places that make giftedness rather than as places that merely find and nurture it. (p. 181)

Siegler and Kotovsky, summarizing some of their findings in *Conceptions of Giftedness,* imply that an "end-state of giftedness should be embodied in a model of gifted performance" (1986, p. 435). Perhaps in a work signifying a talent? Recall that the students undertaking originative inquiry have to use research-productive ability as evidenced in their papers which makes them "creative contributors to a field."

In the spirit of Bridgman's "methods of intelligence" (1949), then, this operational definition follows: Science talent in high school students is demonstrated in originative works rooted in the self-testing and self-correcting code of scientific inquiry.

The definition stems from the essential methodology of the scientist: Originative inquiry leads in its successful end state to a work that encompasses the methodologies that inspirit it—and quarrels with none. This is the premise that has affected practices within 48 states and a large body of teachers and their colleague-scientists and 50-odd years of judging by the many panels of scientists who have evaluated submissions to the Westinghouse Science Talent Search.

Talent in science is unlike that in music, art, or mathematics—where specialized aptitudes can be readily recognized in the young (Csikszentmihalyi & Robinson, 1986). Science proneness begins, I believe, in the base of a general giftedness and develops its component skills in verbal, mathematical, and, in time, the nonentrenched tasks of problem seeking, finding, and solving in specialized science fields. Eventually, given favorable ecologies, science proneness can shift to an expression in a work showing science talent. Prodigies in scientific research on the order of Mozart in music, Leonardo in art, or Courant and Newman in mathematics have been rare (Feldman, 1991); although perhaps the 15- and 16-year-old finalists in the Science Talent Search could be so designated.

This definition of talent in science calls for identification through in-context evaluation in long-term inquiry without reference to IQ or standardized tests of achievement. It provides for testing of science talent through a criterion sample of work of the young as predictive of their future accomplishments (Feldman, 1974, 1986; McClelland, 1973; Renzulli, 1992; Tannenbaum, 1983; Wallach, 1976). Support for this definition is strongly implied in Sternberg's (1985) conception of real-world testing.

A Shift in Self-Identification

A search for these young may then begin early, well before they express a talent in research-productive activity. The methodology enables identification—by adults and by the young themselves—of those students who exhibit the desired attitudes and abilities in idea-enactive, inquiry-oriented behaviors early on before their entry into high school. A similar process of self-identification is inherent in the operation of the revolving door identification model (Renzulli, Reis, & Smith, 1981). Both methods engage the teacher in a mode of qualitative research; teachers observe as students during lessons select themselves for further involvement. See Walters and Gardner (1986, p. 36) and Feldman (1991, p. 223).

There may be an early set of sequences of observable activities in learning, unlike, but similar in consequence, to those in music, in art, and mathematics (see Csikszentmihalyi & Robinson, 1986). Originative contributions in science require the acquisition of a broad knowledge base experientially impossible even for the most precocious child; however, a general giftedness may, if the activating environment is encouraging, eventually choose to express itself in a career in science. The following sequence shows a portent of science talent in young demonstrating focused high-level ability in both acquisition of knowledge and a capacity for inquiry:

> ***First***, during the early school years, some children exhibit raw, unfocused giftedness: Their amorphous potential seems in search of a purposive expression of talent.
> ***Second***, like others' signs of a preference for music or art, some students exhibit a definitive focus towards science (see indexes in idea-enactive, inquiry-oriented lessons and identifiers through correlative activities). Thus the science prone may shift from showing raw ability to demonstrating domain-specific interests, not necessarily excluding their attraction to other fields.
> ***Third***, given a choice later in high school (without pretest), such young may select themselves for participation in a course of study that calls for rigorous acquisition of knowledge and offers opportunity for research-productive originative inquiry.

Fourth, such young may complete an originative work and submit it to a definitive test: The scrutiny of a panel of scientists.

Such students have a solid conception of *themselves,* are secure in their *self constructs,* and employ *transformative power* (Gruber's terms, 1986). They make a choice among the potentialities claiming their recognition within self. Further experience may highlight other choices—for there are talents still to be discovered in individuals seeking excellences as yet unknown or untested. (On this see Gruber, 1986, p. 255.) This conception embodies giftedness not as a free-floating, generality-seeking definition but as an end state in a domain-specific talent. *It is easier to measure talent expressed in a work, talent that presupposes a certain giftedness, than to try to infer from general giftedness raw traits that will project a specific talent.*

In this position, I concur with Sternberg and Davidson's introduction to *Conceptions of Giftedness* (1986). They write that if ever there were "a field that needed 'bringing together' this one is it." Their book, a vade mecum to all who would do research in the field of giftedness and domain-specific proneness and talent, "provided 17 different conceptions of the construct, that, although distinct are interrelated in certain ways." In their original propositions on the difference between implicit and explicit theory, Sternberg and Davidson state,

> Explicit theories presuppose definitions, and seek to interrelate such definitions to a network of psychological or educational theory and data. Such theories are testable by the usual empirical means, and thus may be falsified. But the definitions upon which they are based cannot be falsified, so it is important in evaluating the explicit theories to be sensitive to the underlying conception of giftedness that has generated the theory and data, and to evaluate whether this conception is a useful one.
>
> Ultimately, usefulness may be the only test we have of what makes for a better or worse conception of giftedness. (1986, p. 3)

The last sentence is significant. Toulmin (1961) in *Foresight and Understanding* suggests that the usefulness of inquiry to the evolution of science be measured by its "adequacy," saying "science as a whole, its activity, its aims and ideas evolve by variations and selections." Ravetz also suggests that scientific solutions need to "be assessed for adequacy" (1971, p. 153). Perhaps the broadest criterion to be applied in evaluating a conception (or theory) is its adequacy. A conception of science talent is useful according to its adequacy in meeting specific human needs; if viable, this talent develops and, as a matter of course, evolves by variation and selection.

A Feasible Catalyst?

A newer sequence in curriculum and instruction is possible and should be tested in long-term use and research.

First—Elementary school sequences within the revolving door identification model and idea-enactive, inquiry-oriented teaching and learning may be complemented by computer-assisted interactive videodisk technologies. The early grades (up to grade five, perhaps) should be open to all for purposes of self-identification and self-selection.
Second—Middle schools might well offer a sequence of curriculum and instruction combined in science and mathematics, in idea-enactive, inquiry-oriented, and computer-assisted methodologies, beginning with the fifth or sixth grades.

Entering this sequence should require no pretest; instead, free choice of curriculum and instruction could identify the science prone. They could select a fast-paced program in science throughout the middle school grades. After self-identification and self-selection, they might then wish to continue with fast-paced science-math programs in the late middle school or in the high school, or . . .
Third—Science prone students might select themselves for a program of originative inquiry in the late middle school or high school years, coupled with a rigorous program in acquisition of knowledge planned with those students who demonstrate commitment to science careers.

The critical thinking and behavior demanded by originative inquiry, testable and falsifiable in the course of the program and in the completion of a work, should then be adequate indexes of an early expression of science talent.

In Sum

A powerful program of teaching and learning can be—or should be—a transforming experience and engage as catalyst the young in the shifting from gifts into talent. This conception lies within the postulates of Feldman's stage-shifts in the development of talent (1959), Gruber's formulation of "transformative power" (1986) as comprising giftedness into creativity, Renzulli's enrichment model (1977), and Borland's (1989) and Tannenbaum's (1989) conception of curriculum as identifier of talent. It also accords with my tracing of a path from giftedness to science proneness to science talent facilitated by idea-enactive, inquiry-oriented research-productive teaching and learning. Gruber's theory about the function of exemplary teaching and learning in catalyzing transformative power seems promising.

The definition of talent may be sought within the open opportunities of the transformative power inherent in teaching and learning, active in a full exposition of fields of human endeavor. Let the child in optimum modes of instructed learning in all fields demonstrate initial proneness and find opportunities to turn it to talent. Surely, early schooling is meant to give children a try at all worthwhile knowledge, skills, and attitudes, in order to allow them the experience to hold on to those creative aspects of life and living that they find good.

Complementing the Conception

My search for a conception reflecting the complex of science talent began early in 1937; my hypothesis, published in 1947 in the *Scientific Monthly,* and my findings in *The Gifted Student as Future Scientist* (1955/1981), described science talent in the young as encompassing genetic, predisposing, and activating factors. The genetic factor predicates an interaction of heredity and environment that underlies high-level ability in the student's learning in general and in science in particular. The predisposing factor first appears in the "questing" that seems to stem from dissatisfaction with common explanations of reality. The activating factor comprises the ecologies of achievement described in this study.

The predisposing factor is readily apparent in the distinct difference between the high-ability young who choose differentiated instruction and students in classes who take science to fulfill a graduation requirement. As indicated earlier, once a concept is under preliminary discussion, the science prone tend to go beyond the information given through deeper study: They find texts more complex than usual in high school, often more sophisticated than books intended for freshman in college. The desire of the science prone to know in advance is like that of scholar-scientists; so is their precocious awareness of ambiguities in past history.

Out of this probing and desire to predict comes a concurrent conclusion that science is in constant advance, that most (if not all) explanations are temporary and replaceable by others standing on surer facts and theories. Thus, the science prone young's predisposition to understand discrepant events. Thus, their desire to seek and find that which would fit the as yet unknown.

The interpenetrating collaboration of teacher and student as scholars and as lifelong learners, along with the three ecosystems that form the enabling environments of teaching and learning, make up a whole. As noted earlier, in any ecology, particularly in language-communicable human structures, the parts are not severable; in the human ecology as in any other, even apparent opposites within a given environment interpenetrate each other. The interconnectedness central to an ecology cannot be set aside—even when factors *seem* distant and separate.

We are not limited by inherited behaviors. Learned behaviors can engender connection and interpenetration of seeming opposites; the brain can hold alternatives (Bateson, 1979; Toulmin, 1977). Human behavior cannot be posited either as pure hereditarianism or as pure environmentalism; the two mingle inextricably (Gould, 1981). Because the brain can hold alternatives, it and its product, mind, can engage in constant interconnected probes generating new conceptions in discovery and its indistinguishable correlate, creativity.

In sum: A triad of inseparable factors can result in the expression of science talent:

1. students with promising intellective and nonintellective factors (MacKinnon, 1962; Tannenbaum, 1983)
2. teacher/mentors with the high-level abilities and personalities necessary to develop the optimum instructional and curricular environment
3. the three ecosystems that support necessary curriculum, instruction, and physical facilities

One teacher at Forest Hills remarked on how thoroughly "life affirming" such students were. And, as students often noted on questionnaires, the teachers were "inspiring." Students also checked that "the teachers act as surrogates for parents." Parents, board members, visitors, scientists—the members of the family-school-community, cultural, and college-university ecosystems—saw the profound bonds between teachers and students.

Links and Pauses Within the Sequence of Discovery

If the skein of discoveries in genetics described earlier were severed for any reason (lack of a necessary technology, for example), the result would have been woefully incomplete. In every year, many noteworthy links were forged. During the years between Hooke's discovery and Crick and Watson's findings, thousands of scientists, seasoned researchers, neophytes, and artisans wove the skein of discovery that came to be summarized as the work of a select number of eminent scientists. Now, however, *Science* (the journal of the American Association for the Advancement of Science) frequently prints multiple papers identifying different genes and their functions as interpreted by numerous biological and biochemical disciplines. The probe into DNA continues to be based in an increasingly surer conception that rests, for the uninitiated, in an amazing technology.

There is little doubt that a good number of scientists are deservedly eminent because of their major insights in seeing a field whole. Such men and women contribute major discoveries that create new scientific fields for thought and action. Some of their names become eponyms for a period of discovery: Aristotle, Plato, Ptolemy, Copernicus, Mendel, Newton, the Curies, Darwin, Einstein. Further, certain of these eminent persons showed high ability very early. Some turned toward science after what Walters & Gardner (1986) call "crystallizing experiences." Others constructed their extraordinariness themselves (Gruber, 1981, 1986). On probes of child prodigies, see Runco and Albert (1990) and Feldman (1991), who postulates

> By the definition I have used to identify early prodigious achievement—performance in an intellectually demanding field at the level of an adult professional before the age of ten—there has never been a bona fide physics prodigy, or for that matter, a prodigy in any for the natural sciences. There are a number of fields that do not seem to produce prodigies by this strict definition, but in which individuals do show extraordinary promise and capability at relatively young ages. (1991, p. 16)

Possibly among the last are certain of those who chose over the past half century to participate in the Westinghouse Science Talent Search. At ages 14-16, many of the young at Forest Hills showed research-productive behaviors typical of the kind of critical thinking of substantially older graduate students aspiring to their Ph.D.s.

A coherence of events and factors in the ecology of achievement appears to coincide with the lives of prodigious scientists. Given forceful goals, time, educational facilities, and support from the family-school-community, cultural, and university ecosystems, gifted young give promise of becoming talented. If their experience is fortunate, it can intersect with the enabling environment that will catalyze their ability. If not, their potential may remain untapped. Gray's "Elegy Written in a Country Church Yard" laments that "some mute inglorious Milton here may rest." What would have happened, asked Julian Huxley (grandson of the Thomas H. Huxley who was an eloquent exponent of Darwinism during the latter's lifetime), to a Darwin born a hundred years earlier or later? Aristotle could not have asked, however keen his observation, "Is polio caused by a viral or bacterial agent?"

The discoveries of the eminent and their supporters can unite a number of fields into a new interconnectedness. For example, the work of Crick and Watson on the structure of DNA, steeped in genetics and biochemistry, linked the two fields. The substances DNA produces ameliorate certain errant body chemistry; the injection of DNA sequences alters organisms' development; and an entire field of discovery (creativity) is initiated through the discovery of hidden likenesses in the interrelationships within cellular chemistry.

Hiatus in Individual Discovery—Forging Links

Davidson (1986) posits that "many insightful scientists are able to fit their findings together into a coherent package or story. Less insightful scientists often seem not to realize how their various findings are related" (p. 205). Two of Davidson's theories have particular implications for scientists' thought processes: She cites Darwin's theory as an example of the "selective combination" of many preceding theories, and she describes Kekule's vision of the hexagonal structure of the carbon ring (which sprung from his dream of a snake catching its own tail) as "selective comparison."

Davidson's experimental finds on "insight" are testable through experiment. Her discussion of the problem and her thrusts in solution give meaning to anecdotal accounts of scientists in quandaries. For example, my data compiled about the scientists with whom I worked from 1930-1937, 1958-1962, and 1967-1970, record that, in response to the question—"What happens when you're blocked during research?"—many, in effect, said that they quit for a while: "I take off for a few days"; "I play chess"; "We take a vacation"; "I sometimes find the way out after a deep sleep." The young who were part of the experimental group at Forest Hills High School responded somewhat similarly: "I go back to sports awhile"; "I play the piano"; "I read detective stories" (as did Poincaré when he was stymied).

This anecdotal account serves Davidson's probes. Perhaps time away from the work is essential to reach a point of "selective combination" and "selective comparison" of hidden likenesses. Archimedes is said to have discovered the principle of flotation of heavier-than-water objects in his bathtub with a triumphant "Eureka!"

Einstein suggests the play of insight in this remark:

> In the light of knowledge attained, the happy achievement seems almost a matter of course, and any intelligent student can grasp it without too much trouble. But the years of anxious searching in the dark, with their intense longing, their alternation of confidence and exhaustion, and the final emergence into the light—only those who have themselves experienced it can understand that. (Hoffmann & Dukas, 1972, p. 124)

Briskman (1981) emphasizes Einstein's telling phrase—"the years of anxious search in the dark." He conceives the "searching" in terms of a case of blind generation of variants coupled with the selection of successful variants, all under the control of the "job specification of the problem and of the standards required of a solution" (p. 147).

Toulmin's probe in *Foresight and Understanding* in science (1961, p. 10) is again relevant here. Throughout, he posits that the aims and ideas of science evolve "by variations and selections." Davidson's "selective comparison" and "selective combination" within the processes of insight prodded by inquiry describe a similar process. (See also the description of "seeing" or "imagery" of young in inquiry and those of adult scientists described by Roe [1953].)

One could cite endless models of acts of creativity, discovery, conception, all activities of the brain, turned into mind. What remains obscure is this: How does the three-pound brain, in the complexity of its tissues and cell assemblies of neurons and synapses, produce a thought? A concept? An image? Are these not initial and incontrovertible acts of discovery (synonym: creation)? Or to put it another way, how does the mind discover what is not yet obvious to it? Is this an act of our tantalizing "black box" beyond IQ? (Guilford, 1977; Sternberg, 1985).

We know the answer to none of these questions. But it seems that the path both to insight and science talent may be through originative work guided, in constructive affection, by mentors. Then, as Szent-Gyorgyi put it, it may become possible to see what others see but to think what others had not thought. This study postulates that science talent may emerge early in response to the catalyzing functions and the transforming powers of beneficent teaching and learning. The corps of scientists as talented individuals might increase if *all* the young had cumulative experiences in modes of seeing, by observing through inquiry. Then, they might early on be equipped to see the world of discovery in wider context, to think for themselves in wider dimensions, and to think what others have not thought.

The Role of Discovery in Fostering National Eminence

As Gruber (1985) posits, creativity is closely associated with human survival. But so is a criterion of national eminence. In relation to this, Rotberg (1990) offers a criterion of excellence in research that rests in part on the determination of rates of production of works of research as measured in scientific publications. U.S. publications in science and engineering from 1973 to 1986 have remained nearly steady at about 35 percent of the world's production. The next highest ranking nations: Japan, the former Soviet Union, and the United Kingdom, each provide approximately 8 percent. Rotberg, using National Science Board data (1989), sees America's numerous publications as indicators of leadership in many disciplines: clinical medicine 40 percent; biomedical research 38.4 percent; biology 38.1 percent; chemistry 22.2 percent; physics 30.3 percent; earth and space sciences 42.6 percent; engineering and technology 37.3 percent; mathematics 40.3 percent.

"Indeed, it is generally acknowledged that no other system of higher education offers breadth and quality of the research opportunities available to students in U.S. institutions," Rotberg continues. She quotes Servan-Schreiber and Simon (1987) as asserting "For the first time in modern history, one country seems to serve, in the advanced sciences, as the university of the world" (p. 300).

In studies and researches in giftedness and talent in the making of "human-made capital" the United States' total demonstrates its leadership. Present increases in the flow of publications, as well as in new scientific fields in the postindustrial era, may be indexes of an influx of the young. Students flock here to study from countries across the globe. At the higher levels, America's colleges and universities are world class in training talented scientists and technicians. Not all will become giants—but neither are they dwarfs, a pejorative term perhaps best abandoned.

What of the future? Lederman, warns that "From one institution to the next, across the demographic categories, across disciplines of research, the nation's scientists are sending a warning. Academic research in the United States is in serious trouble." He adds that "this troubled mood is so pervasive that it raises serious questions about the very future of science in the United States" (1991, p. 4).

And the excellent training in science and engineering at the graduate level is not at present generally manifest in the nation's precollege science education. Lederman (1992) and Saltman at the University of California, San Diego (Barinaga, 1991) have mounted initiatives to retrain science teachers—in the hope this precedent will spread over the nation.

Toward a Foothold Conception of Talent

Bell (1992), addressing "American Intellectual Life 1965-1992," posits that "intellectuals today—those who shape and transmit words and ideas—are all within the social structure" (p. 79). A huge number show talent in finding and conserving knowledge. They and their organizations constitute what Bell calls "the institutional life of the society." Briefly, he counts about 350,000 social scientists (of whom about 200,000 are psychologists and 120,000 are economists); 395,000 natural scientists; and 730,000 mathematicians and computer scientists. In the nation's approximately 3,600 institutions of higher learning work some 700,000 college and university teachers; more than 10,000,000 students are enrolled in degree-credit programs; an additional 5,000,000, in other college courses. These numbers do not include the some 200,000 librarians, the more than 80,000 authors, the approximately 60,000 technical writers, and innumerable artisans.

They discover new facts, correct them, and place them in conceptual contexts in new knowledge. They conserve the new knowledge as it is converted into larger conceptual schemes and then expanded through new research and revisions of older judgments. They then redact the conceptions that remain stable for a time in publications, lectures, textbooks, and gatherings of scholars. Then, they watch and, in the course of discovery, turn by paradigm shifts into newer directions. This advance, these changes, can be disconcerting to those who think of science as the discovery of steadfast truths. I cannot think of a scientist who would not agree that the only certainty is uncertainty.

In Sum: A Surer Conception of Talent?

Human talent leaps out of its definition and redefines itself in more formidable expression. In time, the community of scholars engaged in research will probably decipher the human genome, particularly in its specificity in identifying the DNA components of intelligence. In time, the newer insights of the neurosciences will uncover how the meshing of physical, chemical, and physiological functions of neurons, synapses, and neurohumors function in intellection and how they create a thought, an idea, a letter, a musical notation, or a concept. In time, scientists will unearth how the three-pound brain with its 10^{12} or 10^{14} neurons and, possibly, 10^{24} synapses creates the encompassing mind. In time, researchers will develop a social invention that assures equitable access to fulfillment of human worthwhileness to unimpeded limits in pursuit of individual powers of excellence.

In time, then, we will see that what seems to remain true longest in the human scheme is that the young keep coming. And, in time, one or more of the young—always together with one or more of the old— will discover how to do what seems to escape us only to the time of its discovery. As long as the young keep coming, a surer conception of talent is foretold. As long as the young keep coming, so does the permanent agenda to search for superordinate ecologies of achievement.

Epilogue

Renzulli and Reis (1991) warn of the "quiet crisis" in the schooling of the gifted. This time, the crisis is accentuated within a general crisis in schooling and education compounded by the turbulent postindustrial era.

Some 60 years ago, Alfred North Whitehead, distinguished mathematician and philosopher of science, gave us a warning, which is still relevant:

> When one considers in its length and its breadth the importance of this question of the education of the nation's young, the broken lives, the defeated hopes, the national failures, which result from the frivolous inertia with which it is treated, it is difficult to restrain within oneself a savage rage . . . . Today we maintain ourselves. Tomorrow science will have moved forward yet one more step, and there will be no appeal from the judgment which will then be pronounced on the uneducated. *(Aims of Education,* 1929; p. 25)

Postscript: Writer to Reader

My Path to This Study

Half a century of observation and study of school-communities have led toward the conclusions I have offered here about certain ways of stimulating students prone to science to expressing talent in its wide-ranging fields. During those years, I was fortunate in opportunities to study both scientists at work and scientists in the making. Generous latitude in time and resources for studies of methodologies in scientific research and for pertinent observation and testing of curriculum and instruction in school, college, and university allowed me to study in-depth programs and practices for the science prone and science talented.

Toward Early Expression of Science Talent: "Crystallizing Experiences"[21]

My entry into university study after high school (finished in 1929) was interrupted by an illness that led serendipitously to years of early experience in scientific research. During treatment in hospital laboratories, I became acquainted with a chemist who befriended me, encouraged my interests, and sponsored me for a summer job as boy Friday in the Littauer Pneumonia Research Laboratory. Fascinated both by the work and the biochemists ready with explanations, I asked to stay on, was hired, and earned my baccalaureate in evening, afternoon, and summer classes. During my four years in the laboratory, first as an apprentice and then as an assistant in research, I was credited in several research papers.

Thus, before beginning my doctoral studies, I had spent four years observing and assisting in a variety of researches on the biochemistry of *Pneumococcus* and had practical experience in the well-ordered empiricism of research, including the processes and protocols of problem finding and solving. My individual research in the microecology of protists and in the ecology of host-plant fungus relationships in the Plant Pathology Laboratories of the Brooklyn Botanic Garden gave me foothold knowledge into the complexities of micro- and macroecologies. While gathering my data and teaching biology at New York University, I made time to visit several high schools to give presentations to science clubs. In some of the students who attended these secondary school seminars, I thought I saw burgeoning science talent.

I had always wanted to teach and was able to do so both by day at New York University and in the evenings at Teachers College, Columbia University. I was persuaded that, as I had learned research methodology through experience, so could student volunteers in high school. Thus, with the help of George Washington High School's dedicated science teachers, I inaugurated an afterschool program (1937-1938) with a junior-senior science society. In 1944, after several years of pilot study, as chair of the science department at Forest Hills High School, I instituted a similar program, which lasted 10 years.

Early Feasibility Studies

In 1951, Harvard president J. B. Conant and science professor F. G. Watson invited me to assist in a course on the teaching of science there. Fifty selected teachers and

[21]Gardner's term.

32 supervisors from across the country attended courses and seminars in 1952 and 1953 (see Brandwein, 1955/1981, pp. 63-70, "Who Teaches Them"). As part of the course, it was my responsibility to repeat and demonstrate to the class experimental procedures and research techniques of certain historical figures (Lavoisier and Boyle, for example) in juxtaposition to Conant's case histories of discovery and in relationship to his conceptual-schemes approach to the sciences. The Conant experience motivated me to undertake similar work in curriculum and instruction throughout the country.

At the same time, I was gathering data for my 10-year study (1944-1954) of Westinghouse Science Talent Search participants; this research led me to conclude that programs to evoke early expression of science talent were as feasible in strongly differentiated curricular and instructional strategies located in general public high schools as in special science high schools.

In 1954, I left teaching in high school for wider opportunities. I continued to develop materials for curriculums and instruction; I taught and conducted seminars at various universities and schools; what I learned, I applied to my understanding about stimulating interest in and evoking talent in science. Three experiences were particularly formative in this regard.

First, my work with 14 scientists (biologists, physicists, psychologists) in the Sputnik Science Talent Project (1958-1962) clarified my understanding of science talent. I was a member of the Committee of Biological Sciences Curriculum Study (BSCS) team that developed curriculum and instruction in biology. The BSCS Gifted Student Committee, which I chaired, gathered research investigations from 40 scientists for high school students. I also served as a member of the Science Series of the Physical Science Study Committee (PSSC), assisting in development of programs for the science prone and science talented.[22]

Second, in 17 television programs (National Broadcasting Corporation, 1962), I was able to ask 17 young experimenters about their work and the kind of teaching that had aided them in the West and Midwest; then, in consultation, I worked on an additional four programs. I particularly learned from the students (through the questionnaires they completed as part of their admission) and from informal discussions of their respect and admiration for their teachers.

Third, at Colorado College (1963-1970), I had the opportunity to plan and direct four summer programs for some 30 selected talented science students.

From Classrooms to Publishing and Back

After leaving virtually full-time work in schooling, I turned for the next three decades to publishing, mostly in the area of science education. From 1957-1981, I had the opportunity and obligation to observe and investigate teaching, learning, curriculum, and instruction throughout the country and overseas for Harcourt Brace Jovanovich. While at

[22]Both the biology and physics groups published volumes of background materials and investigations supplied by researchers throughout the United States. Resulting were four volumes: *Research Problems in Biology,* by 40 contributing scientists. These were later republished as *Investigations for Students,* (first edition 1965; revised edition 1976). Some 12 volumes by individual scientists in the Physical Sciences Study Series were published by Anchor Books, Doubleday and Co. over a number of years beginning with *Magnets* by Francis Butter (1959).

Harcourt, I spent as much time as possible in classrooms in schools and colleges, maintaining close contact with students, teachers, and their wider communities. As required by the Code of Standards of the Council of American Survey Research Organizations, I have maintained the anonymity both of the students and their schools. When teachers and university collaborators have published their reflections or otherwise made them available, however, I have cited them.

During this period, I studied instructed learning in its variety of modes of presentation. With the aid of consultant-teachers, I observed a core of 600 schools from 44 states. The objective—to learn first-hand about policies and practices in curriculum and instruction. I watched and learned, we discussed, and I taught many demonstration lessons.

I worked, first as senior science editor for the College Department (1954-1968), to develop undergraduate programs in biology, chemistry, and physics based on my visits to 92 colleges.

Then, as president for the Center of Study of Instruction (1967-1970), I directed the development of a complete preparatory elementary program in the sciences, the social sciences, and the humanities. With a group of consulting teachers, I taught its uses for self-identification and self-selection for various abilities. Next, as director of the School Department and director of research in curriculum and instruction (1970-1976), and, finally, as copublisher, (1977-1981), I visited schools on five continents to observe advanced programs in instructed learning.

During these years, I also, upon invitation, conducted seminars in various universities and school districts. Over a third of a century, making an average of 36 school visits per year of observation and investigation to about 1,000 schools, I clarified the conception that underlies this study of the *ecology of achievement* that is the result of the family-school-community ecosystem acting in mutualism with the cultural and university ecosystems. Further, through my study of 600 institutions representative of the broad spectrum of American schooling, I saw directly the disparities in resources and factors that affected curriculum and instruction, teaching and learning, within limiting and enabling environments.

In intensive visits to these 600 schools, I noted frequently the presence of what the National Science Teachers Association summarized in 1983 as the 10 "commonly recurring problems" in science education, which I am calling the Syndrome of 10. The major practices: Lecture-textbook-laid out laboratories in high school and the general absence of science programs in the elementary schools. The exceptions: The advanced practices of about 130 secondary schools, some of them represented in listings of select science high schools and heterogeneous high schools with differentiated science programs listed in Tables 3 and 4. Both kinds of schools are discussed in this study. Some of them were practicing the revolving door identification model enrichment programs.

My observations and field research guided at Harcourt the development of the idea-enactive, inquiry-oriented, and research-productive modes of nonentrenched teaching and learning implemented in a number of the schools I visited. The conceptual schemes approach to instructed learning also served as a means of encouraging students to identify themselves for further work in a number of fields.

In the planning and start-up operation of some 93 programs designed to evoke science talent, I refined my understanding of the major problems and first solutions in the conduct of family-school-community programs for the talented in the sciences and humanities in the United States and overseas.

A distillation of my studies and observations over 50 years come together on these pages. Here I have offered certain of the tested, revised curricular and instructional policies and practices useful in planning programs for developmental stage-shifts from general giftedness —-> science proneness —-> an early expression of science talent in the secondary school years.

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Appendix A: Paths to Science Proneness and Talent

Paths to Science Proneness and Talent

This short list rests on the belief that science programs with effective curricular and instructional modes can help the young identify and select themselves as science prone with the capability of eventually expressing science talent. Thus, a high-caliber science program—coupled with effective training in literacy and numeracy—can act to promote stage shifts as the raw experiences of generally gifted children develop into self-identification of their science proneness.

Teachers of science prone and science talented young are called to develop curricular and instructional learning materials that offer paths to research-productive activity in early and late elementary, middle, and secondary grades.

Materials for Beginning Instruction

The following does not offer an inflexible curricular or instructional sequence but suggests laboratory activities and materials that can evoke science proneness. These frameworks may be adapted in many ways—compacting, fast-pacing, and the like—to individualize teaching and learning for children who have identified themselves as science prone. They may also be used up to grade four to evoke this kind of self-identification. Such curriculums at their best provide raw experiences in hands-on, minds-on processes that elicit the enactive-iconic-symbolic activities that enable identification.

1. *Insights: A Hands-on Science Curriculum* for elementary and middle schools is available through the Educational Development Center Inc., 55 Chapel Street, Newton, MA 02160.
2. *The Science Curriculum Improvement Study (SCIS),* a program of laboratory studies which was developed during the Sputnik crisis, emphasizes activities that evoke early expression of science interest. A revised version is available through Delta Education, Inc., P.O. Box 915, Hudson, NH 03051.
3. An updated version of *The Elementary Science Study (ESS),* written at the same time, is available through the same company.
4. See my discussion with Morholt and Abeles of originative work directed in concept seeking and forming (Brandwein & Passow, 1988, pp. 273-305). In the same volume also appear studies of identification through curriculum and instruction by Passow, Sato, Tannenbaum (all 1989), as well as a bibliography for theory, practice, and procedures in the field of giftedness by Morholt and Crow.
5. See also the reference list to this study.

Beginning Experiences to Evoke Science Proneness

1. Science programs built on idea-enactive, inquiry-oriented teaching and learning methods have been found effective.
    - Programs using the revolving door identification model (Renzulli, Reis, & Smith, 1981) work well to identify the science prone.
    - Programs based in the conceptual-schemes approach that emphasizes the interconnectedness of science also help.

2. Bruner's theoretical base (1966) and the philosophy underlying the programs developed by the post-Sputnik groups prove useful. See my relevant publications (1979, 1981).
3. A number of the current curriculums under construction, while—as is appropriate—aimed at all students, could be modified to encourage the science prone to express their identification through science talent. The American Association for the Advancement of Science's *Project 2061: Science for All Americans* (1985/1993/1994) provides a broad framework for all students' study of science and widely related fields K-12. Several other developing science curriculums aim at students at particular levels. Among them are
   - *Scope, Sequence, and Coordination* from the National Science Teachers Association (1992, 1993), while intended primarily for middle and high school students, could be adapted for the science prone at any grade level.
   - The *Biological Sciences Curriculum Program in Science* (Colorado Springs, CO, 1993), intended mainly for middle school students, works from a new paradigm based in computer and videodisk technology. This BSCS project too could serve science prone students at any level.
   - High school students can consult new editions of the *PSSC Physics* and also the *BSCS Molecular Biology,* both available from commercial publishers.
   - High school science teachers intending to help the young express science talent through originative inquiry should encourage their students to supplement their assigned reading with college textbooks and laboratory materials. The science talented are voracious readers in independent study; however, general high school texts offer a quick study of the chosen field and enable students to select specific topics that interest them.

Existing Approaches to Foster Science Proneness and Talent

1. Teachers and administrators developing programs intended to encourage the young toward science through fast pacing may wish to follow patterns suggested by Lynch (1992), Southern, Jones, and Stanley (1993), the Texas Academy of Mathematics and Science, or Advanced Placement courses.
2. Those intending to stimulate originative inquiry should consult Kopelman, Galasso, and Schmuckler (1989). They should also become familiar with the programs run in nearly every state and dependency by the Westinghouse Science Talent Search and administered by Science Service, 1719 N Street, N.W., Washington, DC 20036. The latter provides annual listings of the names and high schools of winners and runners up in the Search. Developers of work-centered science programs may wish to visit (and perhaps emulate) programs in those schools that produce disproportionate numbers of Search finalists; they may also wish to meet with the state Search directors and coordinators.
3. Another valuable source of information is the information bulletin describing new programs offered by the Educational Resources Information Center Clearinghouse for Science, Mathematics, and Environmental Education (Ohio State University, 1929 Kenny Road, Columbus, OH 43210-1080).

4. The publisher of this study, The National Research Center on the Gifted and Talented (University of Connecticut, 362 Fairfield Road, U-7, Storrs, CT 06279) provides general information and holds conferences on education for the gifted.
5. Those who would nurture the young who show early promise in science fields may consult *The Gifted Student as Future Scientist* (Brandwein, 1955/1981) and *Gifted Young in Science: Potential Through Performance* (Brandwein & Passow, 1989).
6. In the main, however, nonentrenched students and their nonentrenched teachers will have to craft the programs and research that will lead to originative work.

Appendix B: A Structure for Science in Elementary School

A Structure for the Elementary School Science Curriculum

CONCEPT LEVEL VI	The amount of energy gotten out of a machine does not exceed the energy put into it.	In nuclear reactions, matter is converted to energy, but the total amount of matter and energy remains unchanged.	Nuclear reactions produce the radiant energy of stars, and consequent change.	Living things depend basically on the capture of radiant energy by green plants.	Man is the product of his heredity and environment.	Changes in the genetic code result in changes in living things.	**CONCEPT LEVEL VI**
CONCEPT LEVEL V	Energy must be applied to produce an unbalanced force, which results in a change in motion.	In chemical or physical changes, the total amount of matter remains unchanged.	Bodies in space are in continuous change.	Living things are adapted by structure and function to their environment.	The cell in the unit of structure and function in living things.	Over the ages, living things have changed in their adaptation to the changing environment.	**CONCEPT LEVEL V**
CONCEPT LEVEL IV	A loss or gain of energy affects molecular motion.	In chemical change, atoms react to produce change in the molecules.	The Earth's matter is in continuous change.	Living things capture matter and energy from the environment and return them to the environment.	A living thing reproduces itself and develops in a given environment.	Living things are adapted to particular environments.	**CONCEPT LEVEL IV**
CONCEPT LEVEL III	The Sun is the Earth's chief source of radiant energy.	Matter consists of atoms and molecules.	There are seasonal and annual changes on Earth.	The Earth's different environments have their own characteristic life.	Living things are related through possession of common structure.	Living things grow and develop in different environments.	**CONCEPT LEVEL III**
CONCEPT LEVEL II	Energy can change from one form to another.	A change in the state of matter is determined by molecular motion.	There are regular changes in positions of the Earth and Moon.	Living things depend on their environment for the conditions of life.	Related living things reproduce in similar ways.	Forms of living things have become extinct.	**CONCEPT LEVEL II**
CONCEPT LEVEL I	Force is required to set an object in motion.	Matter commonly exists as solids, liquids, and gases.	There are daily changes on Earth.	Living things are affected by their environment.	Living things reproduce their own kind.	There are different forms of living things.	**CONCEPT LEVEL I**
	CONCEPTUAL SCHEME A When energy changes from one form to another, the total amount of energy remains unchanged.	**CONCEPTUAL SCHEME B** When matter changes from one from to another, the total amount of matter remains unchanged.	**CONCEPTUAL SCHEME C** The universe is in continuous change.	**CONCEPTUAL SCHEME D** Living things are interdependent with one another and with their environment.	**CONCEPTUAL SCHEME E** A living thing is the product of its heredity and environment.	**CONCEPTUAL SCHEME F** Living things are in continuous change.	

From "The reduction of complexity: Substance, structure, and style in curriculum." Harcourt Brace & Company (1977). Permission to reprint granted by the publisher.

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