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ABSTRACT

This three-part report discusses the concept of intelligence and its importance for educators. Part 1 considers the basic question of what intelligence is. Part 2 discusses the implications of notions of intelligence for schooling, dealing with both the training of content knowledge and the training of intellectual skills. Each of these first two parts is divided into sections which discuss the psychometric view, the Piagetian view, the information-processing view, and comparison and evaluation of alternative approaches. Part 3 presents an outline of a program of instruction for intellectual skills, based upon a particular theory of intelligence. A bibliography is included. (JM)

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Understanding Intelligence:

What's in it for Educators?

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Understanding Intelligence: What's in it for Educators?

The concept of intelligence pervades our daily lives at least as much as does any other psychological concept. Notions about intelligence are particularly pervasive in education. Almost without exception, students will have taken a large number of intelligence or scholastic aptitude tests before completing their education; for many of these students, their level of performance will have had important consequences for their school careers. Paradoxically, although intelligence tests have been widely used in education, the concept of intelligence has not been particularly informative to educators, beyond its use in providing a rough guide to determining reasonable expectations regarding academic performance for students with different levels or patterns of intellectual skills.

The relationship between intelligence and education is of critical importance both to those concerned with educational practice and to those who do research on intelligence. This relationship is of importance to educators because the intelligence of students constrains and informs educational practice. The magnitude of these effects may be underestimated because of the natural tendency to view students largely in terms of their grade levels, which is determined for most students by their chronological age. But it is neither chronological age nor grade level *per se* that requires sequencing, say, calculus, late rather than early in the sequence of mathematics courses. Rather, it is, in large part, students' developed intellectual skills and knowledge. The relationship between intelligence and education is of importance to researchers in intelligence because formal education is a major factor in the development of intelligence. Indeed, intelligence tests are to a large extent measures of achievement for grades a few years earlier than that of the students being tested on a given intelligence test.

The field of intelligence is presently very different from that which gave rise to the technology (primarily intelligence tests) we know so well. Because of this difference, we have reason to suspect that the answer to the question posed in the title of our report is different from, and more favorable than, that which would have been appropriate ten, or even five years ago. This report presents what we believe to be today's answer to a long-standing question, that regarding what's in the concept of intelligence for educators.

Our report is divided into three main parts. First, we consider the basic question of just what intelligence is. One cannot meaningfully discuss issues of assessment and training of intelligence without first discussing what it is that needs to be assessed or trained, and so we deal with this question in some detail. Second, we consider the implications of notions of intelligence for schooling. Our consideration deals both with the training of content knowledge, which is currently emphasized in our schools, and with the training of intellectual skills, which is emphasized to a lesser degree. Finally, we present an outline of a program of instruction for intellectual skills, based upon our own theory of intelligence.

Because there is no single, universally accepted view of what intelligence is or of what its implications are for assessment and training, we divide each of the first two parts of our review into four sections. The first three sections present alternative perspectives on the question being considered. The first section presents the standard psychometric view, that view which has given rise to intelligence, aptitude, achievement, and other forms of conventional testing. The second section presents the Piagetian view, as developed by the late Jean Piaget and his colleagues. The third section presents the information-processing view, which is probably the most popular one among contemporary cognitive and educational psychologists. This view perceives intelligence as a set of information-processing skills that can be identified and understood throughthe methods of experimental psychological research. The final section presents a comparison and evaluation of the alternative approaches.

What is Intelligence?

The Psychometric Perspective

The psychometric perspective on intelligence is usually traced back to the work of Alfred Binet and his colleagues in France (Binet & Simon, 1905), and subsequently to the work of Lewis Terman and his colleagues in the United States (Terman & Merrill, 1960). Their psychometric perspective sought to understand intelligence by analysis of the increasing ability of children to solve relatively complex problems requiring skills of the sort encountered in everyday experience. In much of the psychometric literature, three concepts have been central to analyzing intelligent performance. The first concept, chronological age, refers simply to a person's physical age from time of birth. The second concept, mental age, refers to a person's level of intelligence in comparison to the "average" person of a given chronological age. If for example, a person performs at a level comparable to that of an average twelve-year old, the person's mental age will be twelve, regardless of his or her chronological age. The third concept, intelligence quotient, or IQ, traditionally has referred to the ratio between mental age and chronological age, multiplied by 100. A score of 100 signifies that mental age is equivalent to chronological age. Scores above 100 indicate above-average intelligence, whereas scores below 100 indicate below-average intelligence.

For a variety of reasons, the concept of mental age has proven to be something of a weak link in the psychometric analysis of intelligence. First, increases in mental age seem to stop at about the chronological age of 16. The interpretation of the mental age concept above this age thus becomes equivocal. Second increases in mental age vary nonlinearly with chronological age even up to the age of 16. The interpretation of mental ages, and of IQ's computed from them, may therefore vary for different chronological ages. Third, the unidimensionality of the mental age scale seems to imply a certain sameness over age levels in the concept of intelligence--a sameness that the contents of the tests do not bear out. Infant tests, for example, measure skills entirely different from those measured by tests for adolescents and adults. Moreover, correlations between performances on the two kinds of tests are usually quite meager. For these and other reasons, IQs have tended, in recent years, to be computed on the basis of relative performance within a given age group: One's performance is evaluated relative only to the performance of others of the same age. Commonly, scores have been standardized to have a mean of 100 and a standard deviation of 15 or 16. These "deviation IQs" have been used in much the same way as the original "ratio IQs," although in spirit they are quite different. In fact, deviation IQs are not even quotients at all!

Whatever its usefulness as a descriptive construct, mental age is of little usefulness as an explanatory construct: It may describe increases in level of performance on intellectual tasks, but it certainly does not explain them. Psychometricians have thus been led to seek alternative ways of conceptualizing the nature of intelligence. One such way has been through the model of factor analysis. Factor analysis is a statistical tool that seeks out common sources of variation among people, and identifies these common sources as unitary psychological attributes, or factors. Different theorists have proposed differing sets of factors to account for the structure of mental abilities.

The earliest view, that of Spearman (1927), is that intelligence comprises a general factor (g) common to performance on all of the various tests that are used to measure intelligence, plus a specific factor (s) involved in performance on each individual test. The number of specific factors, therefore, is equal to the number of tests. A later view, that of Thurstone (1938), is that intelligence is best described as comprising a set of approximately seven primary mental abilities, namely, verbal comprehension, verbal fluency, number, spatial visualization, perceptual speed, memory, and reasoning. On this view, any general factor that exists must be viewed as "second-order," existing only by virtue of correlations between the primary mental abilities. A relatively more recent view, that of Guilford (1967, 1982), is that intelligence comprises as many as 120 factors, each of which involves an operation, a content, and a product. There are five kinds of operations, six kinds of products, and found kinds of contents, yielding the 120 (5 x 6 x 4) factors. Examples of such factors are cognition of figural relations, measured by tests such as figural (abstract) analogies and memory for semantic relations, measured by tests requiring recall of semantic relationships such as "gold is more valuable than iron." Probably the most widely accepted view among factor theorists today is a hierarchical one, which has been proposed by several theorists in somewhat differing forms (e.g., Burt, 1940; Snow, 1978; Vernon, 1971). On Vernon's view, for instance, intellectual abilities comprise a hierarchy, with a general factor (*g*) at the top; two major group factors, verbal-educational ability and spatial-mechanical ability at the second level; minor group factors at the third level; and specific factors at the bottom.

The factor model is obviously able to provide a good structural account of the nature of intelligence. Yet, the influence of the factor model has declined in recent years. There seem to be at least several reasons for this decline (Sternberg, 1977).

First, the factor model provides no mechanism for transition between one level of performance and another, whether the transition occurs as a result of maturation or of learning. Although it can provide information regarding performance at each of two respective levels, it does not provide information regarding the way in which the first kind of performance gives way to the second. Thus, for example, one is given no clue as to how to account for increases that occur in amounts of abilities represented by factors, or as to how to account for the apparent increase in differentiation of factors that occurs with increasing age (Garrett, 1946).

Second, the model has not been terribly successful in explicating the processes involved in intelligent behavior. Intelligent behavior presumably reflects at least in part the outcomes of mental processes, but factor analysis leaves one with little or no idea of what these processes are. Factor analysis is a structural model, and its strength lies in providing a picture of how abilities are organized. But any inferences regarding process usage made on the basis of factor analysis are highly indirect, and an account of structure without process is highly incomplete. Hence, the outcomes of factor analysis can be viewed as yielding an incomplete account of intelligence.

Third, factor analysis has certain statistical weaknesses that render the interpretation of factor-analytic outcomes equivocal. The inferential machinery for disconfirming factorial solutions is not well-developed, making it difficult to distinguish between alternative factor-analytic models. Moreover, factorial solutions are subject to arbitrary rotation in space. Imagine a "factor space" containing a set of axes and points having various coordinates along those axes. The interpretation of the points (usually tests) will obviously depend upon their spatial locations with reference to the axes. But the axes are mathematically arbitrary: Only the placement of points in the space is fixed. As a result, different theories, corresponding to different placements of the axes in the factor space, can be viewed as accounting for the data equally well, at least from a mathematical point of view. Attempts to use methods other than factor analysis to distinguish among factor theories that differ from each other only by the placement of axes in a factor space have been scarce, and not particularly illuminating.

To conclude, the factorial model of intelligence is of some, but limited, usefulness. Its strength seems to lie in its ability to provide a picture of how abilities (at some level of analysis) are organized. Its weaknesses lie in its inability to provide a unique picture, in its inability to account for information processing, and in its failure to specify how transitions occur. An alternative framework for conceptualizing intelligence, that of Piaget, seems to fare better on all of these accounts.

The Piagetian Perspective[1]

The Piagetian perspective on intelligence is usually viewed as independent and distinct from the psychometric one, but in fact, it in some ways arose out of and in reaction to it. Jean Piaget first entered the field of cognitive development when, working in Binet's lab, he became intrigued with children's wrong answers to Binet's intelligence test items. To understand intelligence, Piaget reasoned, one's investigation must be twofold. First, as was done by Binet, one must look at the way a person acts upon the environment--at a person's performance. But also, and here is where Piaget began to part company with Binet, one must consider why the person performs as he or she does--at the cognitive structures underlying the individual's actions. Through his repeated observation of children's performance, particularly their errors in reasoning, Piaget concluded that there are coherent logical structures underlying children's thought, but that these structures are different from those underlying adult thought. In the six decades that followed, Piaget focused his research on delineating what these cognitive structures might be at different stages of development and how they might evolve from one stage to the next.

Piaget thought that there are two interrelated aspects of intelligence: its function and its structure. Piaget, a biologist by training, saw the function of intelligence as no different from the function of other biological activities, that is, adaptation, which includes assimilating the environment to one's own structures (be they physiological or cognitive) and accommodating one's structures to encompass new aspects of the environment. "A certain continuity exists...between intelligence and the purely biological process of morphogenesis and adaptation to the environment" (Piaget, 1952, p. 1). In Piaget's theory, the function of intelligence--adaptation--provided this continuity with lower biological acts. Piaget rejected the sharp delineation proposed by others between "intelligent" acts, which were suggested to require insight or thought, and "nonintelligent" acts, which were proposed to require only habits or reflexes. Instead, he preferred to speak of a continuum in which "behavior becomes more intelligent as the pathways between the subject and the objects on which it acts cease to be simple and become progressively more complex" (Piaget, 1976).

Piaget further proposed that the internal organizational structure of intelligence, and of how intelligence is manifested, differ with age. Piaget divided the intellectual development of the individual into discrete, qualitatively distinct stages. As the child progresses from one stage to the next, the cognitive structures of the preceding stage are reorganized and extended, through the child's own adaptive actions, to form the underlying structures of the equilibrium characterizing the next stage. Piaget proposed three distinct stages of development: the sensorimotor stage (which lasts from birth to approximately two years of age), the period of preparation for and organization of concrete operations (which is often subdivided into a preoperational and a concrete-operational stage, lasting approximately from age two to age twelve), and the formal-operational stage (which is begun at approximately age twelve and which continues through adulthood) (Piaget, 1976). Because of space limitations, we will not describe Piaget's stages of intellectual development here. Instead, we refer the reader to summaries by Flavell (1963) and Ginsburg and Opper (1979); a more dense account can be found in the original works of Piaget (1970, 1976).

Underlying Piaget's descriptions of the child's intellectual development are three core assumptions about the nature of the developmental process. First, on Piaget's view, there are four factors that interact to bring about the child's development. Three of these factors are the ones usually proposed: maturation, experience of the physical environment, and the influence of the social environment. To these three factors, Piaget added a fourth, which coordinates and guides the other three: equilibration, that is, the child's own self-regulatory processes. Thus, Piaget's theory centers on the assertion that the child is a very active participant in the construction of his or her own intelligence. Second, Piaget asserted that this intellectual development results in the appearance of developmental stages and that these stages follow an invariant sequential order, with each succeeding stage incorporating and extending the accomplishments of the preceding stage. Third, although the rate of development may vary across children, the stages themselves and their sequence were considered by Piaget to be universal. In sum, Piaget's theory asserted that there is a single route of intellectual development that all humans, regardless of individual differences, follow. Individual differences results from different rates of progression along this route, or from individuals stopping along the way rather than following the route to completion.

It would be difficult to overestimate the impact Piaget's theory has had upon thinking about intellectual development. Yet, the theory seems to have become somewhat less influential during the last several years. In part, this decline may be attributed to the rethinking and revisionism that inevitably follow some years after any major breakthrough. But there seem to be more substantial reasons as well for the decline.

First, the explanatory value of the concept of a stage of intellectual development has been called into serious question (see, for example, Brainerd, 1978). On the one hand, the concept of a stage is useful because of the apparent emergence of groups of related behaviors that are qualitatively different from the behaviors that preceded them. On the other hand, the concept of a stage is vitiated by the clearcut development that occurs within as well as between stages. Piaget and his colleagues account for this within-stage development in two principal ways. The first is through the postulation of substages. The other is through the postulation of horizontal décalage, by which abilities such as seriation or transitivity are allowed to develop slowly rather than to appear all at once: Abilities permeate slowly through the various content domains to which they can be applied, rather than appearing in all of these content domains simultaneously. For example, seriation with sizes might precede seriation with shadings. The problem, of course, is that as the borders between stages are blurred, the usefulness of the stages as explanatory constructs decreases.

Second, although the stages may explain individual differences across childhood age levels reasonably well, they seem inadequate to explain individual differences beyond early adolescence, and particularly, between adults of the same approximate age. Differences in intellectual performance among adults remain striking, despite the fact that most of them can be presumed to be formal-operational. Either the stage construct is inadequate, or at least one additional stage must be postulated (see, for example, postulations of "fifth" stages by Arlin, 1975, and Case, 1978). The inability of the theory adequately to account for individual differences among adults inevitably casts a shadow on the validity of its characterization of individual differences among children. Presumably, the sources of individual variation are not totally different between adults, on the one hand, and children, on the other.

Third, certain aspects of the theory seem simply to be incorrect. Obviously, no theory will be correct in all its aspects. But some of the most fundamental tenets of Piagetian theory have been challenged in recent years, with apparent justification. An example of such a challenge is that of Trabasso (Bryant & Trabasso, 1971; Trabasso, 1975) to the notion that transitivity is impossible before the stage of concrete operations. In a series of ingenious experiments, Trabasso and his colleagues have provided strong evidence that failure of preoperational children to solve transitive inference problems is due to memory rather than reasoning limitations. When memory demands are removed from the task, preoperational children do appear to be able to perform transitive inferences. This is only one of a number of examples of instances in which Piaget's theory seems inadequately to account for existing data.

Fourth and finally, Piagetian theory seems to be far more applicable to the mathematical and scientific thinking of children (and particularly of older children) than it does to their thinking in disciplines such as literature and history. This bias in the coverage of the theory manifests itself in the tasks that have been investigated. Almost all of the tasks administered to concrete- and formal-operational children are logical and scientific in nature. A complete theory of intellectual development, however, would need to say more about the development of more intuitive forms of thinking than does Piagetian theory in its present form.

To conclude, the Piagetian model of intelligence is of considerable usefulness. But its usefulness, like that of the psychometric model, is limited. Its strength seems to be in its detailed account of the development of scientific forms of thinking, and in its well worked out mechanisms for transitions between levels of development. Its weaknesses are in its limited applicability to nonscientific forms of thinking, in probable errors in the reasons postulated for certain behaviors, in its inability to account for individual differences among adults, and in certain weaknesses of the concept of the stage.

The Information-processing Perspective

Information-processing conceptions of intelligence have in common their view of intelligence as deriving from the ways in which people mentally represent and process information. Such conceptions have often used the computer program as a metaphor and heuristic for understanding how humans process information. Although the history of the information-processing approach is often traced back to Donders (1868), who proposed that the time between a stimulus and a response could be decomposed into a sequence of successive processes, the modern history of the approach goes back only to 1960. Two seminal works appeared in that single year: Newell, Shaw, and Simon's (1960) "report of a general problem-solving program," and Miller, Galanter, and Pribram's (1960) monograph on Plans and the Structure of Behavior. These works each proposed theories of information processing, and proposed that these theories could be implemented and tested via digital computers. Newell, Shaw, and Simon actually presented a program, the General Problem Solver (GPS), that could solve difficult reasoning problems, using only a relatively small number of algorithms and heuristics.

Whereas many psychometric theorists of intelligence have agreed upon the factor as the fundamental unit in terms of which intellectual behavior should be analyzed, many information-processing theorists have agreed upon the elementary information process as the fundamental unit of behavior (Newell & Simon, 1972). It is assumed that all behavior of a human information-processing system is the result of combinations of these elementary processes. The processes are elementary in the sense that they are not further broken down into simpler processes by the theory under consideration. The level of analysis that is considered to be "elementary" will depend upon the type of behavior under consideration, and the level at which the theory attempts to account for the behavior.

The notion of an elementary information process is obviously a general one. Some investigators have sought to specify further the notion and the ways multiple elementary information processes might combine in task performance.

Consider first Miller, Galanter, and Pribram's (1960) proposal of the TOTE (Test-Operate-Test-Exit) as the unit of interest. Each unit of behavior begins with a test of the present outcome against the desired outcome. If the result of the test is congruent with the desired outcome (called an Image), an exit is made. If not, another operation is performed in order to make the result of the next test conform as closely as possible to the Image. If the result of the next test is congruent with the Image, an exit is made. Otherwise, still another operation is performed, and so on down the line until a test results corresponds to the Image (which may have been modified along the way in order to make it conform more closely to the demands of reality).

Sternberg (1980, in press-b) has expanded the notion of an elementary information process in a somewhat different way, suggesting that processes can be viewed as being of three basic types--metacomponents, performance components, and knowledge-acquisition components. Metacomponents are higher-order control processes that are used for executive decision making in problem solving. They include processes such as deciding upon the nature of the problem being confronted, deciding upon a strategy for task performance, and correctly interpreting external feedback. Performance components are the processes actually used in task performance. They include processes such as encoding the terms of the problem, inferring relations between these terms, and comparing al ative possible solutions. Knowledge-acquisition components are processes in learning new and consequential information. They included processes such as selective encoding, by which one distinguishes relevant from irrelevant information that one encounters in material to be learned. and selective comparison, by which one relates information one has just encoded to old information that was already part of one's knowledge base.

Newell and Simon (1972) have proposed yet another expansion of the elementary information process, suggesting that information processing can be understood in terms of the operation of "production systems" having productions as the basic constituent units. A production is a condition-action sequence. If a certain condition is met, then a certain action is performed. Sequences of ordered productions are then called production systems. The "executive" for a production system is hypothesized to make its way down an ordered list of productions until one of the conditions is met. The action corresponding to that condition is executed, and control is returned to the top of the list. The executive then makes its way down the list again, trying to satisfy a condition. When it does so, an action is executed, control returns to the top, etc.

Despite their currency and considerable popularity, information-processing conceptions of intelligence seem to be limited in several important respects. First, the concentrated focus upon cognitive processing has led to a neglect of motivational, environmental, and other variables that limit the operation of intelligent functioning. A computer may not be troubled by insufficient motivation or constraints placed by environmental distractions--people are so troubled. Second, whereas factor models have been criticized for emphasizing structural considerations at the expense of process ones, information-processing models might be criticized for the reverse: They seem to provide little or no structural system to take the place of the factors of psycnometric theory. Third, questions of transitions in intellectual development seem insufficiently to have been worked out. Whereas several investigators have attempted to indicate how information-processing constructs could account for transitions from one state to the next (e.g., Anderson, 1976), none of these accounts match Piaget's for sensitivity to and credibility regarding developmental issues. Fourth and finally, information-processing accounts, like Piagetian theory, have tended to focus upon very analytic kinds of intellectual functioning. No one has a viable information-processing account of literary or artistic talent, nor is it even clear what form such an account would take.

In conclusion, the information-processing approach to intelligence has provided a major step forward in our understanding of intelligence. It has specified intelligent functioning with a degree of precision and testability unrivaled by other accounts. But the approach is lacking in a number of respects, particularly in its insufficient regard of motivational and environmental variables, in its skimpy accounts of structural matters, in its incompleteness in accounting for transitions in intellectual development, and in its concentration upon analytic functioning.

Comparison and Evaluation of Perspectives

The similarities and differences among the three approaches to defining the nature of intelligence can perhaps best be pointed out by comparing how they would account for performance on a single type of problem. Consider, for example, an analogy of the form A : B :: C : (D_1, D_2), such as DOCTOR : PATIENT :: LAWYER : (judge, client). Analogies have been found to be among the best single indicators of overall intelligence (Reitman, 1965; Spearman, 1923; Sternberg, 1977; Whitely, 1977), and so provide a particularly apt illustrative example.

A psychometrician would attempt to understand performance on the analogy by examining the underlying factors of intelligence that contribute to individual differences in performance. A believer in Thurstone's (1938) theory of primary mental abilities might identify these factors as verbal comprehension (since the terms of the analogies are words) and reasoning (since it is necessary to reason with the words). He or she might then postulate that differences in people's ability to solve analogies can be accounted for differences in their levels of verbal comprehension and, especially, reasoning abilities. Note that in this approach, the analysis of intellectual behavior (a) employs a structural model, (b) concentrates upon variation among individuals, (c) employs standard IQ tests (in this case, most likely Thurstone's Primary Mental Abilities test) to assess intelligence, and (d) assumes that performance on a given task is an additive function of a set of underlying abilities expressed as factors.

A Piagetian would attempt to understand performance on the analogy by understanding the logical operations underlying analogy solution, and by identifying stages leading up to satisfactory analogy solution. In fact, Piaget, with Montangero and Billeter (1977), has suggested three stages in the development of analogical reasoning. In the first stage, characterizing the performance of children of ages 5 and 6, children can understand relations between pairs of terms, but ignore higher-order relations between pairs. Thus, although these children can link A to B or C to D, they cannot link A-B to C-D. In the second stage, characterizing the performance of children from about 8 to 11 years of age, children can form analogies, but when challenged with countersuggestions, they readily rescind their proposed analogies. Piaget interprets this finding as evidence of a weak or tentative level of analogical reasoning ability. In the third stage, characterizing the performance of children from age 11 and up, children form analogies, are able to state explicitly the conceptual bases of these analogies, and resist countersuggestions from the experimenter. Note that in this approach, the analysis of behavior (a) employs a model of the development of schemes for problem solving, (b) concentrates upon what is common to individuals of a given age, but not common to individuals of different ages, (c) employs a clinical method (usually observation) to assess intelligence, and (d) assumes that performance on a given task can be understood in terms of the availability of logical functions for problem solving.

An information-processing psychologist would attempt to understand performance on the analogy by examining the processes that contribute to performance, and that make some analogies more difficult than others. In my own theory, for example, (Sternberg, 1977; Sternberg & Gardner, in press), an individual's performance would be analyzed as requiring <u>encoding</u> of the terms of the analogy, <u>inferring</u> the relation between the A and B terms (DOCTOR and PATIENT), <u>mapping</u> the higher-order relation that links the first half of the analogy to the second (the DOCTOR half to the LAWYER half), <u>applying</u> the relation previously inferred from A to B so as to create an ideal completion to the analogy (say, CLIENT), <u>comparing</u> the answer options to see which is closer to the ideal answer (in this case, one of the options is identical to the ideal), and responding. Note that in this approach, the analysis of intellectual behavior (a) employs a process model, (b) concentrates upon variation in item difficulties, (c) employs tasks that usually have to be presented by computer in order to decompose response time into its constituent parts, and (d) assumes that performance on a given task is an additive function of a set of component processes, whose component latencies add up to yield total latency.

We believe the three approaches to understanding intelligence are largely complementary rather than mutually exclusive. Indeed, it can be shown that their forms of analysis map into each other (Sternberg, 1982). Hence, we see no need to "choose" among approaches. Rather, a better goal would be to view each as dealing with different, but overlapping aspects of intelligence. The question then arises as to whether there are aspects of intelligence that are neglected by all three approaches, and that thus are being slighted in contemporary cognitive science.

We would define intelligence as the purposive selection of and adaptation to real-world environments relevant to one's life. This definition has several implications. First, intelligence is defined in relation to real-world environments. None of the three approaches has seriously dealt with tasks and task performance that are relevant to the everyday world. To the contrary, the tasks that have been studied have tended to be rarified and even contrived. Second, intelligence is defined in terms of the environment as it is relevant to one's life: Intelligent behavior in one culture may be quite different from intelligent behavior in another culture, depending upon the demands of the culture and its surroundings. But the kinds of problems that have been studied seem to have little relevance to most people's lives, aside from the testlike situations in which they are presented. Third, intelligence is defined in terms of selection of and adaptation to environments. Although the tasks and theories that have been proposed may be vaguely related to such skills, they seem very removed from them. The ability to answer analogies, or to answer vocabulary questions, may well be predictive of real-world adaptation. But none of the tests or theories deal directly with selection and adaptation, which is what we believe intelligence is about. Finally, we believe intelligence is purposive: One shapes one's life according to plans, both short-term and long-term. Although current theories and tests may assess planning skills, the plans assessed are at a much more microscopic level than the kinds of plans we believe are relevant to selection and adaptation in real-world environments.

Our conclusion, then, is that theorists and technologists have to get out of laboratories and into the real world, whether it is the world of the school or the world of the adult worker. We do not believe that current theories and tests have no value: To the contrary, they seem to deal well with intelligence as it relates to the internal environment of the individual: The theories aptly decompose intelligence into its constituent parts. Where the theories seem to fail is in their ignoring of the relation between intelligence and the external environment in which intelligence functions. Intelligence does not operate in a vacuum, but rather in a world that is constantly increasing in complexity. If our understanding of intelligence is to have any relevance for understanding the interface between the individual and this world, it will have to study the functioning of the individual in this world, rather than merely in a laboratory or on a standardized test. Studying such functioning is much more difficult than studying functioning under highly controlled conditions such as characterize a psychologist's laboratory. But we fear that unless the leap is made, psychologists--together with their theories and tests--will be left far behind in a rapidly changing world. Their notions of intelligence and intelligence testing may continue to develop, but in ways progressively more out of touch with the real world. We believe the time has come to bring the world into testing. Ideally, this day would have come before testing was brought so prominently into the world.

What Implications does Intelligence have for Education?

What implications for intelligence can be derived from the alternative approaches we considered in the preceding part of this report? We now turn to this central question, dealing in turn with each of the psychometric, Piagetian, and information-processing approaches. We shall divide our consideration of each approach into two major sections. The first section will deal with deriving educational objectives; the second section will deal with reaching educational objectives. Each of these two sections will in turn be further divided into two subsections, one concerning the development of intellectual skills, the other concerning the development of knowledge and knowledge-related skills.

Educational Implications of the Psychometric Approach to Intelligence

The psychometric approach to intelligence has been intimately related to education since the turn of the century. Indeed, Alfred Binet's work on intelligence testing began with his commission to identify children who would be unable to profit from normal instruction in the public schools of France. Since Binet's time, the testing movement has always been very closely linked to educational goals and to the educational establishment.

Deriving educational objectives: Intellectual skills. Many intervention programs have been aimed at the goal of improving intellectual skills, especially programs at the preschool level whose purpose has been to make children more ready for formal schooling (see Bronfenbrenner, 1975; Gordon, 1975; and Palmer & Anderson, 1979, for comprehensive reviews of such programs).

Project Head Start is perhaps the most conspicuous example of such a program. The program provided activities designed to facilitate language development and to enhance performance on a variety of tasks similar to those found on intelligence tests. The program had other equally important goals.

such as the provision of health services and social development (see Zigler & Valentine, 1979, for a comprehensive review of the program). There was no one Head Start curriculum, and in fact, no one has been in a position to say just what the experiences in most of the centers were like (Miller, 1979). A survey conducted by the Office of Child Development in 1972 identified more than 200 curricula, many of which were used in Head Start classes either singly or in combination.

Although it is not possible to speak of a single Head Start curriculum, one can identify program models that were adopted by multiple Head Start centers. One such model is a program developed by Carl Bereiter and Sigfried Engelmann at the University of Illinois in 1966 (Bereiter & Engelmann, 1966). The curriculum was essentially a crash program designed to build the skills that would be needed for first-grade work. The program in fact resembled a first-grade class more than did most other programs. The program's highly academic emphasis can be seen by considering just a few of the 15 specific minimum goals it set for students (Whimbey, 1975): (a) the ability to use both affirmative and negative statements in reply to the question--what is this?, (b) ability to use the prepositions on, in, under, over, and between to describe relations among objects, (c) ability to perform simple if-then deductions, and (d) ability to name colors. The Bereiter-Engelmann program and other highly academically oriented programs like it seemed to produce greater gains in both IQ and achievement test performance than did the less academically oriented programs.

Because of the great diversity in Head Start centers, it has been difficult to evaluate the success of the program in terms of gains in academically important intellectual competencies. Recently, Lazar and Darlington (1982) completed a longitudinal follow-up on twelve early intervention programs.

These programs were not a random sample of Head Start centers, but rather a clearly nonrandom sample of experimental, research-oriented programs for children from low-income families for which careful documentation was available. Long-lasting effects were reported in some areas, but not others. Some of the main conclusions were:

1. Performance on the Stanford-Binet Intelligence Scale was higher for children in the programs than for children who served as controls and did not participate in the programs. The gains lasted for several years after the completion of the programs, but eventually disappeared. Follow-ups 10 to 17 years after the programs ended found no significant differences between program and control children.

2. Children who attended the programs were less likely to be assigned to special education classes and were less likely to be retained than were control children.

3. The programs resulted in improved attitudes toward school performance on the part of students and their mothers.

Another approach to intellectual-skills training is that provided by Guilford's Structure-of-Intellect (SOI) Model (Guilford, 1967). The model, mentioned earlier, classifies intellectual factors according to contents (figural, symbolic, and semantic), operations (cognition, memory, evaluation, convergent production, and divergent production), and products (units, classes, relations, systems, transformations, and implications). Guilford and his associates have devised tests purported to measure most, but not all of the factors gotten by crossing all possible combinations of contents, operations, and products. Meeker (1969) devised a means of describing performance on individual intelligence tests in terms of the SOI model and provided guidance on use and interpretation of the model.

An example of a longitudinal implementation of the SOI model is the Glendora Unified School District Project (Valett, 1978). Norms have been determined for children 5 to 12 years old on numerous short tests designed to test the SOI factors. A profile is constructed for each child on the basis of his or her test performance, and a prescriptive educational program is then implemented. A number of games, activities, and curriculum materials have been constructed for the purpose of remediation of weaknesses. Initial results suggest that children in the program do significantly better when later tested on the SOI tests than do comparable control children.

Another program based on Guilford's model is Think (see Valett, 1978). The Think curriculum is used with elementary and secondary school students who demonstrate a weakness in conceptual abilities. The program has been designed especially to develop six thinking skills: thing making (mental processes for becoming aware of and naming things), qualification (recognizing the unique sensory, emotional, or logical aspects of a thing), classification (sorting into groups on the basis of common properties), structure analysis (dividing things into constituent parts), operation analysis (dividing events into phases or stages), and seeing analogies (recognizing similarities between relationships). Evaluation of the program suggests that students participating in it improve in language and reading skills.

It has been argued that an important reason for the popularity of the IQ as a measure of program effectiveness--and of IQ tests as the bases for program curricula--is that it became obvious that virtually any intervention program, even one lasting only six weeks, all but guaranteed an increase in IQ of about 10 points (Zigler & Seitz, 1982), or more (Hunt, 1971). These gains may not reflect intellectual skill differences, however. It seems likely that the programs effected motivational changes and improvements in test-taking skills, as well as or possibly instead of improvements in cognitive skills (Seitz, Abelson, Levine, & Zigler, 1975; Zigler, Abelson, Trickett, & Seitz, 1982.) This explanation is consistent with the common finding that the gains are lost when children leave the programs. The subsequent loss has led Zigler and Seitz to recommend that interventions be directed at improving family support systems, since such systems would be a necessary (although clearly not sufficient) condition for maintenance of gains, at least through a child's schooling.

Deriving educational objectives: knowledge and knowledge-related skills. The product of the psychometric approach as applied to knowledge and knowledge-related skills is the standardized achievement test. An example of such a test is the Stanford Achievement Test. This test, like others of its kind, is used for diagnosing strengths and weaknesses in the past learning of individual students, groups of students, and school curricula. In particular, test scores can be used to generate educational objectives for students with weaknesses in particular content areas. The areas covered by the Stanford--vocabulary, reading comprehension, word study skills, mathematics concepts, mathematics computation, mathematics applications, spelling, language, social science, science, and listening comprehension--are typical of such tests.

More specific tests have also been designed that provide diagnostic information in more limited academic areas. For example, the Stanford Diagnostic Reading Test provides scores for literal reading comprehension, inferential reading comprehension, vocabulary, sound discrimination, blending, and rate of reading. Although the information provided by specific diagnostic tests such as this one is quite precise, the lack of emphasis on process in the psychometric approach presents a problem for prescribing educational objectives: Without an understanding of the processes used, say, in sound blending, it can be difficult to generate a prescription regarding exactly how teaching and learning should proceed.

Reaching educational objectives: Intellectual skills. How can tests be used in the schools, particularly with regard to assessing the interface between intellectual skills and schooling? Several suggestions have been made in this regard. One set of suggestions derives from Glaser (1976, 1980). Glaser has proposed that the interface between testing and schooling can proceed according to any one of five different models:

1. Selective, fixed-track model. Tests are used to judge whether a student has the initial competence needed to succeed in an instructional program. If the initial competence is present, the student is admitted to the program; if not, the student is designated a poor learner and is not admitted to the program. This has been the traditional approach to dealing with intellectually handicapped children. Until recently, such students would be routinely excluded from regular public school programs.

2. Development of initial competence model. This model includes all aspects of the first model plus an additional aspect. If, upon initial testing, the student does not demonstrate the competency required for program entry, a remedial program is instituted for the purpose of improving the competency to the point where the student can enter the program. Federally funded remedial reading and mathematics programs are examples of this model: Students who do poorly on standardized reading and mathematics tests are eligible to receive remedial help. (In the pure case, students would not be allowed into regular programs until the initial required competence was fully demonstrated.)

3. Accommodation to different styles of learning model. This model is similar to the first model, except for the fact that several programs are offered, each with its own test of competence for being admitted to the program. A student could be admitted to any program for which the required competence

was demonstrated. The idea is that a learner could find a program that accommodates his or her particular style. At first glance, tracking in public schools might appear to be an example of this model. But such tracking is a poor example, because tracking generally takes into account only rate, not style, of learning.

4. Development of initial competence and accommodation to styles of learning model. As the name suggests, this model is the third one with the added provision that students who do not demonstrate competence for being admitted to any of the programs are given an option to receive remediation that will eventually enable their admission.

5. Alternative terminal attainments model. This model is the fourth with the modification that students must not all meet the same terminal criterion. This model is illustrated by high schools that award different diplomas depending upon the nature and level of student accomplishments.

Another set of suggestions regarding the uses of standardized IQ tests in the schools has been put forth by Resnick (1979). She has suggested that three purposes could be served by standardized tests in the management of instruction:

1. Sorting function. Tests are used to determine who gets into which program.

2. Grading function. Tests are used in conjunction with grades in school to assess how well a student is learning. Often, a student is labeled an "underachiever" if high IQ test scores are accompanied by low grades and/or achievement test scores.

3. Monitoring function. By monitoring is meant the assessment of performance during a program for the purpose of making adjustments in the program or its implementation. According to Resnick, standardized tests do not serve this function well, since they do not provide the precise determination of what has been mastered and what should come n that this function would ideally require.

Reaching educational objectives: Knowledge and knowledge-related skills. The psychometric approach can be used for the purpose of reaching educational objectives related to the development of knowledge and knowledge-related skills when it provides information (often in the form of test scores) that can be used to describe the instructional program that would best suit a particular learner.

A substantial body of research on aptitude x treatment interactions (ATIs) addresses the issue of matching instruction to learner characteristics. ATI refers to interactions of instructional treatments with individual differences in learner characteristics. A thorough review of the ATI approach and studies done under this approach can be found in Cronbach and Snow (1977). We provide here only two illustrative examples.

The first is a recent study by Peterson, Terence, and Swing (1981) on interactions between intellectual ability and large versus small group instruction in fourth and fifth grade students. Students were taught a two-week geometry unit in either a large or a small group situation. A significant curvilinear aptitude-treatment interaction was reported, with high and low ability students doing better in the small group condition than in the large group condition. Medium ability students did slightly better in the large group condition. This result is explained in terms of high and low ability students benefiting relatively more from peer tutoring processes that occur in small group instruction.

A second study (Janicki & Peterson, 1981) examined the interaction of direct instruction (as in a classroom) versus a small-group variation of direct instruction with learner attitudes and locus of control. Locus of control refers to beliefs about the extent to which important life events are under one's own control. An ATI was reported in which students with more positive attitudes and an internal locus of control were better in the small-group variation of direct instruction than in the classroom variant. The explanation offered was that the small-group setting offered more opportunity for choosing activities and exerting control over learning.

Comprehensive reviews of the ATI literature suggest several limitations in what, in theory, would sound like an ideal approach for relating intellectual characteristics of the learner to instructional treatments (see Cronbach & Snow, 1977; Snow, 1976, 1977; Tobias, 1976, 1977). First, the literature is filled with inconsistent and seemingly unreplicable results. Very, very few results have had even one replication across subjects and experimenters. Second, there is some question regarding the generality of ATIs. Cronbach (1975) has suggested that they may be specific to time and place. Third, an ATI study requires a tremendous amount of statistical power (i.e., ability to reject the null hypothesis if it is false), and few of the studies that have been done have had the statistical power they ideally should have had. Fourth, there is often a gap between the theory generating the study (where there is any theory at all!) and the experimental operations used to test the theory. As a result, the studies are often only minimal tests of the hypotheses they set out to investigate.

Dissatisfaction with the results of ATI studies has led to at least two relatively recent developments: (a) an increased interest in learner control of instruction, and (b) attempts to identify the underlying information processes common to performance on aptitude tests and instructional settings. These two developments may well result in a set of more positive and more replicable results. But we believe that at present, the gap between what is tested in IQ tests and what is taught in schools--both in terms of knowledge and skills--is sufficiently large that it will be difficult indeed to bring the two together.

<u>Summary</u>. To summarize, the psychometric approach to intelligence has been closely linked to the schooling process ever since Binet's original development of his test for identifying retarded individuals who would not profit from normal instruction. The links between the psychometric approach and schooling have taken a number of forms, many of which we have considered in this chapter. To the extent that the linkage has not always succeeded, we believe that several problems can be identified as hindering the flow of information from tests to schools and back again. First, the tests do not provide the kinds of information about process that seem to be necessary for an effective training program that seeks, in fact, to train students in the processes (or products) of learning. Second, a large gap exists between the kinds of microprocesses required on IQ tests and the macroprocesses required for school learning. Although the tests may well be predictive of such learning, it would be difficult to argue that IQ tests tap directly the skills involved, say, in writing a paper. Third, motivational and situational limitations intervene between test and school performance to further reduce the relationship between the two. Until a theory and measurement of motiv .ion can be brought into the assessment process, tests of purely cognitive functioning will only be highly limited predictors of school accomplishment. Fourth, there has been a notable gap between theory and practice. The links between psychometric theories of intelligence, on the one hand, and both tests and training programs based on these theories, have been tenuous at best, obscuring whatever relationships the theories may have to existing technology. Fifth and finally, much of the research that has been done that has sought to link theory to practice has been seriously flawed (see, e.g., the review in Cronbach & Snow, 1977). Even if strong links existed, it is not clear that they would regularly be found, if only because of inadequacies in the designs of existing studies. As a result, the fruitfulness of linking psychometric

theory to educational practice is still in need of stronger demonstration.

Educational Implications of the Piagetian Approach to Intelligence

Piaget and his Genevan collaborators have not been primarily interested in the implications of Piaget's theory for educational practice (Duckworth, 1979a, 1979b; Elkind, 1974; McNally, 1974). Rather, their interest has been primarily in epistemology, the area of philosophy concerned with the nature and origin of knowledge. American educators and psychologists have been largely responsible for bringing Piagetian theory into the educational arena, and they have done so in a manner that has resulted in a considerable amount of tension between what can be regarded as Genevan and American views.

American educators and psychologists were interested primarily in how to speed up the development of Piagetian "intellectual structures," which typically develop slowly. The Genevan position was that this acceleration was not possible, a position that was later modified slightly to the position that some, but very limited, learning of intellectual structures could take place. The issue of whether Piagetian structures can be trained has stimulated a considerable body of research (see Beilin, 1971, 1977, for reviews of this literature), but the issue remains unresolved at the present time.

One of the reasons the issue may have remained unresolved is that it has been difficult not only to derive prescriptions for educational practice from the theory, but difficult also to derive proscriptions (Klausmeier, 1979). The first large-scale attempt to apply Piagetian theory to education can probably be traced to the Woods Hole Conference of 1959 (see Bruner, 1961), which was seminal for a number of the sweeping educational reforms of the 1960s. Examples of curricula based at least in part on Piagetian ideas of intellectual development have included the New Math, Minimath, Science Curriculum Improvement Study Guide, Project Physics, and Man: A Course of Study (see Klausmeier, 1979).

Deriving educational objectives: Intellectual skills. Piagetian theory has often been interpreted as implying that a goal of education should be to propel children into subsequent developmental stages of intellectual growth earlier than they would enter these stages on their own. Piagetian theory can thus be seen as providing a sense of what kinds of skills should be taught to a child at each level of development. Efforts to improve intellectual skills have generally focused upon either the concrete-operational period or the formal-operational period, and have been "American" in their emphasis on acceleratic

In the concrete-operational period, mental operations are designated as concrete because they are tied to concrete objects. The capacity for abstract thought is not yet fully developed, although the ability to reason inductively is fairly well established. Children during this period have acquired both "reversibility" and "seriation." Reversibility is shown by the children's abilities to add and subtract (which are "reverses" of each other), their abilities to multiply and divide (again reverses), and their abilities to conserve. Conservation of quantity (or volume) is demonstrated by a child's ability to recognize that a fat, short glass holds the same amount of water as a tall, thin glass from which the water was poured. Similarly, children will realize that regardless of the shape into which a ball of clay is twisted, the amount of clay remains invariant over the various shapes. Children during this period of intellectual development also acquire the abilities to seriate and to make transitive inferences. The ability to seriate allows children to order objects along various dimensions--from short to tall, from light to dark, from fat to thin, etc. The ability to make transitive inferences enables a child to infer, for example, that if John is taller than Pete, and Pete is taller than Bill, then John is taller than Bill.

A number of programs have sought to have children reach the period of concrete operations in the preschool, and thus before the usual age of 6 or so when concrete operations typically begin (Bingham-Newman, Saunders, & Hooper, 1976; Kamii & DeVries, 1974; Lavatelli, 1970a, 1970b; Silverman & Weikart, 1973). Evaluation of these approaches indicate that children in the programs do indeed reach the period of concrete operations, but it is not clear they actually do so earlier than do children who are not in the programs (Kuhn, 1979a). Moreover, there is no evidence at all that earlier attainment of the concrete-operational period results in earlier attainment of the subsequent period of formal operations, which we consider next.

In the formal-operational period, usually beginning at the age of 11 or 12, children acquire the ability to reason abstractly, without reference to concrete objects or events. Children become able to reason from the general to the specific (deductively), and thus to use the peculiar blend of inductive and deductive reasoning that characterizes scientific inquiry. During this period, children acquire the ability to comprehend second-order relations of the kind used in reasoning by analogy (i.e., relations between relations). This period is often characterized as the first one to enable children to contemplate not only what is, but what might be (Kuhn, 1979b). Examples of formal-operational reasoning include constructing an argument for a position you may not support, using proportional relationships to determine whether the economy size box of cereal is really more economical than the regular size, and determining what time you are likely to reach your destination on an automobile trip by taking into account your present rate of travel.

Formal-operational thinking is of particular interest to educators for two reasons. First, formal-operational thinking is required for a full understanding of academic disciplines such as physics, mathematics, and literature (Chiapetta, 1976; Collis, 1971; Griffiths, 1976; Peel, 1976), as well as for many examples of everyday reasoning (Capon & Kuhn, 1979; Kuhn & Brannock, 1977). Second, there are data to suggest that less than half of all high-school students, college students, and adults are fully capable of formal-operational reasoning (Chiapetta, 1976), although this percentage may vary somewhat as a function of an individual's familiarity with the particular task (Dasen, 1977; Sinnott, 1975). It is also interesting that whereas there is a correlation between formal-operational reasoning ability and traditional measures of intelligence (Kuhn, 1976), a substantial number of individuals who do well on standardized tests may not yet be fully capable of formal-operational reasoning (Nucci & Gordon, 1979). What makes the attainment of formal-operational reasoning a seemingly inherently more worthwhile educational goal than the early attainment of concrete operations is that whereas all normal individuals eventually attain full concrete-operational reasoning, the same does not appear to be true for formal-operational reasoning. Unfortunately, efforts to train formal-operational thinking are not far enough along yet to permit an evaluation of their effectiveness.

Deriving educational objectives: Knowledge and knowledge-based skills. As difficult as it was to use Piagetian theory to derive educational objectives for the purpose of developing intellectual skills, it is even more difficult to use the theory when one's purpose is to develop knowledge and knowledge-based skills. Piagetian theory is fundamentally a developmental theory of intelligence. The theory views learning in the educational sense as being limited to specific tasks and of only secondary importance to the learning of generalized skills (Lawton & Hooper, 1978).

Piagetian theory as manifested in educational setting has typically involved a program of thinking activities included in addition to the usual reading, writing, and arithmetic (Furth & Wachs, 1974; Kuhn, 1979a). As yet, there is little integration of Piagetian thinking activities with traditional academic disciplines, with the possible exception of several science-oriented programs (e.g., Karplus, 1974; Lawson, 1975). Even in these programs, the links between the theory and program are often somewhat tenuous. . .

Reaching educational objectives: Intellectual skills. With what has been described as the Genevan position on the futility of developing intelligence as an educational objective, it should come as no surprise that implications for reaching educational objectives are not easily found.

One approach would be to attempt to diagnose intellectual level with tasks that measure a variety of Piagetian concepts, and then to tailor remedial instruction accordingly. Tuddenham (1970), for example, has constructed a battery of Piagetian tasks to measure intellectual level. This approach has been largely rejected by adherents of Piaget's theory as being (a) impractical, especially if the preferred practice of individualized clinical assessment is used; (b) unwise, because it is doubtful that training of intellectual structures is possible; and (c) against good educational practice, because learning is inhibited when externally imposed tasks are used, as would be the case in most training programs (Duckworth, 1979a; Furth, 1970; McNally, 1974; Piaget, 1970). Moreover, it is probably a mistake to infuse Piagetian tasks into the school curriculum because such tasks are simply indicators of level of cognitive functioning. Klausmeier (1979) has proposed the analogy that teaching Piagetian tasks is like teaching specific items on an intelligence test for the purpose of developing intelligence.

Reaching educational objectives: Knowledge and knowledge-based skills. The theory does serve as a useful source of educational implications for reaching objectives in the development of knowledge and knowledge-based skills. Consider four general implications of the theory.

1. Active discovery is preferable to passive, receptive learning. Piaget (1970) has made a distinction between two types of schools. Traditional schools are characterized by work being imposed on students from external sources, usually the teacher. For both Piaget and Dewey, work imposed by others is the antithesis of intrinsic interest and therefore of learning (McNally, 1974). Some have charged American educators and psychologists with being preoccupied with the study of the effects of the environment on an individual who is conceived of as being nothing more than a passive recipient of information (e.g., Reid, 1979). "Activity schools," on the other hand, are characterized by active discovery learning. Students learn in situations by actively working on something--by attempting to obtain a practical result that they can then understand (Athey & Rubadeau, 1970; Duckworth, 1977a; Reid, 1979).

Overall, Piaget's view of education is quite similar to the experimentalist position of John Dewey (1968). This position holds that knowledge develops from activity, and more specifically, from applying the scientific method to whatever problems the environment has to offer. The steps of learning involve (a) becoming aware of the problem; (b) clarifying the problem; (c) proposing hypotheses for solving the problem; (d) reasoning out the implications of each hypothesis; and (e) testing each hypothesis (McNally, 1974).

The sharp distinction made between traditional schools and activity schools is perhaps overly simplistic, but the point being made is an important one. The Piagetian view seems clearly to lead to a preference for the kinds of programs today found in open, rather than in traditional schools (Lawton & Hooper, 1978

2. Motivation is fundamentally important. This implication follows from the view that in any learning situation, it is the learner who is doing most of the work, not the teacher. What is of particular interest is that the concept of motivation is deeply embedded in the functioning of the cognitive structures.

Motivation derives directly from the operations of the intellectual structures (Furth, 1970). According to Piaget, those things are most interesting that pose moderate novelty to the individual, and thus to which the individual's cognitive structures can be accommodated: Too little novelty is a bore; too much novelty passes the individual by.

This view suggest the great importance of matching the task to the child's cognitive structures; but the question remains as to how best to go about doing this. Because one cannot know precisely the cognitive structures that an individual brings to a situation, it is usually recommended that a wide variety of tasks be made available, and that the children given the tasks then be watched in order to determine what grabs their interest. Those tasks that interest particular children are those most likely to be well matched to their existing cognitive structures (Farnham-Diggory, 1972; McNally, 1974).

3. Learning situations must be practical. Practical situations are precisely those that correspond to an individual's natural activity (Duckworth, 1979a). Learning in schools should not be different from an individual's natural form of learning about the world. The most that schools can do is to encourage students to think about things they might not have thought about thinking about on their own. A closely related point is that what is practical is also that which is concrete, at least until the stage of formal operations. Manipulative activities with concrete materials are therefore to be recommended, at least until the stage of formal operations (Ginsburg & Opper, 1969).

4. Flexibility is essential. The best learning situations are those that permit the learner to establish plans for reaching a distant goal, where wide latitude is given as to permissible approaches or paths to reach the goal (Athey & Rubadeau, 1970; Duckworth, 1979a).

Summary. The educational implications of Piagetian theory have been difficult to come by, because Piaget's theory is a theory of intellectual development rather than of learning in the educational sense of the word. Thus, if the theory does not have clear implications for education, neither was it meant to. We will conclude with a discussion of four reasons why we believe the theory is probably not optimally suited to widespread use in education. We do so at the same time we express our sympathy with the four implications discussed immediately above.

1. The theory is of competence rather than of performance. Competence refers to all that a person is capable of, regardless of internal or external limitations that interfere with the application of this full competence. Performance refers to demonstrated competence. Any number of factors act to limit competence--motivation, external resources, attention, and the like. Educators must deal with manifest performance as well as underlying competence. Otherwise, they will create unrealistic expectations for students. And indeed, Piagetian-based programs seem, if anything, to involve setting expectations that are simply too high for students to reach. The same result could be expected from any educational program based on a theory of competence rather than of performance (Sternberg & Davidson, in press). Duckworth (1979b) has suggested that educators stop trying to develop intellectual structures, and instead be concerned with developing individuals' use of their structures to learn new things about the world. Stated otherwise, Duckworth is arguing that educators pay attention to performance rather than to competence.

2. The long length of time covered by each stage limits the usefulness of the stages for sequencing instruction. The stages may provide general guidelines for, but certainly do not provide specific sequencing for educational objectives. The time ranges covered by the stages are simply too great. Although the stages can be subdivided on the bases of identified lags in development (so-called

horizontal décalages), these lags are treated by the theory as anomalies and therefore are of little use in sequencing instruction (Klausmeier, 1979).

3. The theory emphasizes maturation rather than learning. The emphasis in Piaget's theory is clearly upon the unfolding of a preprogrammed set of skills over time. Short shrift is given to learning and environmental influences on learning. Piaget does not ignore the environment: To the contrary, he emphasizes the interaction of the individual with the environment. But the development of cognitive structures is believed to be maturational, and as noted earlier, Piagetians have, if anything, scoffed at attempts to teach these structures.

4. The theory lacks sufficient empirical support to serve, at the present time, as a basis for educational interventions. As noted earlier, the empirical support for Piaget's theory is mixed, at best. As time goes on, successively larger chunks of the theory are being undermined by new data. One therefore must be reluctant to apply the theory to education, lest the interventions fail in part because the theory upon which they are based is incorrect.

In sum, then, educators seeking to apply Piaget's theory to educational interventions would do well to pause before jumping in. At the same time, some of the implications that follow from the theory, particularly those applying to active learning, motivation, practicality, and flexibility, would seem to be well worth heeding. Perhaps the lesson to be learned is that if one is selective in the aspects of the theory used, rather than trying to apply it wholesale, one is much more likely to design a successful, practically feasible educational program.

Educational Implications of the Information-processing Approach

Compared to our attempt to derive educational objectives from the Piagetian perspective, an attempt to derive such objectives from an information-processing perspective is easygoing. The attempt is nontrivial, however, especially because the gap between cognitive psychology and education has been and continues to be quite substantial.

Deriving educational objectives: Intellectual skills. Information-processing theories of intelligence can be used for the purpose of deriving educational objectives by virtue of their provision of a means of decomposing task performance into its underlying mental components. Educational objectives can then be developed for the purpose of improving the efficiency with which the identified information-processing components are executed.

An example of this approach is provided by the work of Whitely and Dawis (1974). Inner-city high school students were trained to solve verbal analogies--problems such as the DOCTOR : PATIENT :: LAWYER : (judge, client) problem given earlier. Students were given training that consisted of various combinations of (a) practice on verbal analogies, (b) feedback as to the correct answers, (c) instruction on topics such as types of analogy relationships (e.g., opposites, functional relations, and the like), and (d) instructions regarding the formal structure of an analogy. Earlier information-processing analyses of analogy performance were used to provide a theoretical basis for the training. Improvement was found on a subsequent test of analogical reasoning for the group that received instruction on relationships, feedback, and instruction on structure. Other studies similar to the Whitely and Dawis one have also reported success in improving children's performance on various kinds of reasoning problems (e.g., Holzman, Glaser, & Pellegrino, 1976; Salomon & Achenbach, 1974; Sternberg & Weil, 1980).

A similar approach has been applied to the task of improving memory performance in mildly retarded individuals. For example, Engle and Nagle (1979) trained mildly retarded fifth and sixth grade students on three strategies for remembering a series of pictures of common objects. A semantic encoding strategy group was instructed to think of the meaning of each item, of a personal experience with it, of its function, and of other items in the list of objects that were in the same category. An acoustic encoding strategy group was instructed to think of the sound of the word and to repeat the initial sound. A repetitive rehearsal strategy group was instructed to repeat the verbal label of the pictures. The choice of strategies to be trained followed from information-processing theories of memory performance. Subsequent performance was best for the semantic encoding strategy group up to seven days after training. A follow-up seven months later found no evidence for the retention of the strategies, although when the strategies were prompted, performance again was superior for the semantic encoding strategy group.

Similar results have been reported by others (e.g., Brown & Barclay, 1976; Butterfield, Wambold, & Belmont, 1973), but demonstrations of durability and transfer of training remain skimpy. When transfer has been tested in retarded individuals, almost none has been found, even for highly similar items and tasks (Resnick, 1981). Whether individuals of normal intelligence would show significantly more transfer than is shown by the retarded remains an unanswered question. Concern over the problem of transfer has prompted a shift in emphasis to the metacognitive level, that is, the level of executive planning and decision processes rather than of lower-order task performance components. Evidence is becoming available that emphasis on metacognitive training does result in some degree of durability and transfer.

Kendall, Borkowski, and Cavanaugh (1980), for example, studied the maintenance and generalization of an interrogative strategy for remembering pairs of pictures of common objects. The strategy consisted of having the child covertly perform four steps for each pair of to-be-remembered items: (a) state a relationship between the items of the pair; (b) ask a "why" question about the relationship; (c) analyze the items semantically (i.e., think about their meaning); and (d) apply the semantic analysis to answer the "why" question. To enhance strategy maintenance and transfer, the training was characterized by (a) active student participation, (b) extended strategy training, (c) semantic processing of item pairs, (d) provision of feedback about the value of using the strategy, (e) use of a large number of examples provided by the experimenter as a means of explaining the parts of the strategy, (f) systematic introduction of the parts of the strategy, and (g) fading of experimenter involvement over the course of the training. The outcome of the study was that strategy maintenance was obtained (at least for a period of a week or so) and that generalization was obtained to a new task in which the student was required to remember sets of three pictures. Although it would have been desirable to use a transfer task less similar to the original task than was this one, given past results, a finding of any transfer at all was impressive. Success with similar approaches to training intellectual skills has been reported by others as well (see, e.g., Belmont, Butterfield, & Borkowski, 1978; Borkowski & Cavanaugh, 1979; Brown & Campione, 1977, 1980; Ross & Ross, 1978).

By far the largest training program based upon information-processing analysis is Feuerstein's (1980) Instrumental Enrichment (IE) program. This extensive program for retarded learners has been employed in a large number of countries, with at least tentative indications of considerable success. Although the program concentrates upon training of performance on IQ-like tasks, it also involves motivational components that encourage retarded performers to work up to their full capacity. Because of the range of the program, a full discussion of it would be beyond the scope of this paper (see, however, Sternberg, in press-a , for a lengthy discussion and evaluation).

In sum, information-processing theories of intelligence permit the decomposition of intelligent behavior into component elements, each of which can serve as a locus for a training intervention. Transfer of training seems to depend at least in part upon training at the metacognitive as well as the cognitive level.

Deriving educational objectives: Knowledge and knowledge-based skills. Just as it is possible to decompose tasks that are believed to measure intellectual skills, so is it possible to use information-processing techniques to decompose tasks that are involved in the acquisition of academic knowledge and skills. The trend toward focusing on metacognitive processes that we observed for intellectual tasks is also evident in the literature on academic tasks.

Rigney (1980) has proposed that the learner is continually seeking answers to six questions: (a) What is it? (b) What should I do about it? (c) How can I do it? (d) Can I do it? (e) How am I doing it? (f) Am I through? For routine events, these questions are asked and answered automatically without the conscious attention of the learner. For other than routine events, answers may not be apparent, which will necessitate applying conscious cognitive resources. Self-monitoring skills identified by Rigney as being necessary for successful performance on academic tasks include keeping one's place in a long sequence of operations, knowing that a subgoal has been obtained, detecting errors, and recovering from errors either by making a quick fix or by retreating to the last known correct operation. Such monitoring involves both "looking ahead" and "looking back." Looking ahead includes learning the structure of a sequence of operations, identifying areas where errors are likely, choosing a strategy that will reduce the possibility of error and that will provide easy recovery, identifying the kinds of feedback that will be available at various points, and evaluating the usefulness of these various kinds of feedback. Looking back includes detecting errors previously made, keeping a history of what has been done to the present and thereby what should come next, and assessing the reasonableness of the present immediate outcome of task performance.

Greeno (1980) has formalized an information-processing analysis of task performance by developing a computer simulation model called Perdix that represents the knowledge required to solve problems in geometry. The program was largely developed by observing ninth-grade students solving geometry problems and thinking aloud as they solved the problems. Greeno identified three domains of knowledge that he believed are required for solving geometry problems: propositions used in making inferences, perceptual concepts used in recognizing patterns, and strategic principles used in setting goals and planning. It is this third domain of strategic principles that is of particular interest to us here. Included in this domain is knowledge of general plans that can lead to a desired outcome. For example, the knowledge that there are three alternative approaches available for demonstrating that two angles are congruent would be an instance of knowledge that can be used for deciding upon a problem-solving strategy.

The views of Rigney and Greeno are representative of a growing number of views that emphasize metacognitive skills in academic performance (see, e.g., Brown, 1978, 1980; Carroll, 1980; Flavell, 1976; Snow, 1980). Metacognitive theorists have in common their belief that teaching specific strategies just won't work, in the long run: One must teach general principles and how to apply them over a variety of task domains.

<u>Reaching educational objectives</u>: <u>Intellectual skills</u>. An implication of recent information-processing work for reaching educational objectives is that metacognitive skills should be trained as well as cognitive ones. An example of a program that follows this implication is one designed to develop general learning ability in university undergraduates (Dansereau, Collins, McDonald, Holley, Garland, Diekoff, & Evans, 1979). The program stresses six executive-level steps to learning that have the interesting, if macabre, acronym of MURDER. The "M" corresponds to setting the mood to study; the "U" to reading for understanding; the "R" to recalling material without referring back to the text; the "D" to digesting the material by amplifying it; and "E" to expanding knowledge by self-inquiry; and the "R" to reviewing mistakes made on tests and practice exercises. Each executive step is associated with a family of substrategies. Students who completed the program performed significantly better on comprehension tests over textbook passages than did students who did not complete the program. This testing took place one week after training, indicating at least short-term durability. Students in the program also reported significant changes in self-report measures of study practices.

Although almost all of the studies that have been done have been done in the school, recent interest has centered on the role of the parents as well as of the school in the development of intellectual skills. In particular, it has been proposed that the parent serves a key role in a child's intellectual development by modeling self-control strategies that are gradually learned by the child over the course of the years of parent-child interaction (Brown & Campione, 1980; Feuerstein, 1980; Wertsch, 1978). Feuerstein has suggested that mediation of learning experiences by the parent is perhaps <u>the</u> critical way in which young children learn.

Reaching educational objectives: Knowledge and knowledge-based skills. The importance of considering metacognitive performance when one's purpose is to develop knowledge and knowledge-based skills is highlighted by the accumulating evidence that students, especially young ones, are not very adept at monitoring what they do when learning. Generally speaking, students blindly follow instructions and do not question themselves in a manner that would lead to efficient task performance (Brown, 1980). Mention will be made of four areas of metacognitive performance that have been found to be problematic for students. (See Brown, 1978, 1980, for comprehensive reviews.)

1. Task difficulty. Students have been shown to be relatively unskilled both in predicting the difficulty of a task and in recognizing when task difficulty changes markedly. For example, Moynahan (1973) found that young children would predict that a noncategorized set of items would be as easy to remember as a categorized set, even though the category structure actually improved their recall performance markedly. Similarly, Tenny (1975) asked kindergarten, third, and sixth grade students to compose lists of words that would be easy to recall. Developmental differences were found whereby the older students were more likely to demonstrate their insight that organization by taxonomic category made lists easier to remember (see also Brown, 1975, 1978; Brown, Campione, & Murphy, 1977; Flavell, Friedrichs, & Hoyt, 1970; Salatas & Flavell, 1976; Smirnov, 1973).

2. Comprehension monitoring. Students have been shown to be insensitive to incomprehensibility and incompleteness of task directions, textual information, and verbal communications. For example, Markman (1977) asked first through third grade students to help in finding a way to teach children a magical trick. The directions for the trick as presented to the students were incomprehensible. After the directions were presented, the students were asked 10 probing questions that determined the extent to which the students were aware of the incomprehensi-

bility of the directions. The older students demonstrated their awareness of the incomprehensibility of the directions with only minimal probing. The younger students often did not realize that they did not comprehend until they attempted to use the directions for actually performing the magic trick. In a different paradigm, Ironsmith and Whitehurst (1978) had kindergarten, second, fourth, and sixth grade students listen to a speaker and then select one of four sets of pictures on the basis of the speaker's message. The students were told to ask questions if they needed more information. The speaker's messages were either informative as to the set of pictures to choose or were ambiguous in that two of the four sets of pictures satisfied the speaker's directives. Kindergarten students responded identically to the informative and ambiguous messages. Second grade students sometimes made general requests for more information, and fourth and sixth grade students often asked specifically for the relevant missing information. Similar results have been obtained in a variety of paradigms (e.g., Asher, 1978; Cosgrove & Patterson, 1977; Karabenick & Miller, 1977; Patterson, Massad, & Cosgrove, 1978; Shatz, 1977).

3. Study-time apportionment. Students have been shown to have difficulty in planning ahead, especially in terms of study-time apportionment. Study-time apportionment refers to how one studies in anticipating a future test, including such things as determining what is important to remember and what is not, choosing a strategy or tactic to improve learning, determining how successful the chosen strategy appears to be, and determining whether or not another strategy should be employed (Brown, 1980). An experimental analogue has been developed to study a simple case of study-time utilization in young children (see, e.g., Brown & Campione, 1977; Masur, McIntyre, & Flavell, 1973). Children are presented the task of remembering a series of pictures over several study trials. After each succeeding trial, the children are allowed to pick only half of the

items for further study. Young children and slow learners were found to pick items for further study at random. Children above third grade were found to select those items that they had missed previously as the target ones for further study. Clearly, their strategy is the wiser one.

4. Predicting one's own performance. Students have been shown to have difficulty in monitoring the success of their performance and in determining when they have studied enough to have mastered the material confronting them. For example, Brown and Barclay (1976; see also Brown, Campione, & Barclay, 1978) investigated the accuracy children exhibit when predicting at what point they could recall without error a series of pictures of common objects. Subjects in their study consisted of educable mentally retarded children with mental ages of 6 and 8. The students were trained in mnemonic memory strategies and were instructed to continue with such strategies until they had mastered the entire set of pictures. Few of the subjects were able to estimate accurately when they had learned the items.

The picture that emerges from these and other lines of research is that young children and retarded children show very little metacognitive awareness. There is some evidence to suggest that older students may also be deficient in at least some metacognitive skills. In a survey study, Anderson (1980) found university students to be more likely to use the study strategy of reading and rereading with some underlining and note-taking than to engage in questioning and surveying activities prior to reading, and to engage in recitation, reflection and review afterwards. Yet, the latter study strategy has been found to be the superior one (Pauk, 1962; Robinson, 1970; Thomas & Robinson, 1972). Students did not report frequent use of commonly recommended strategies such as skimming, summarizing, working practice problems, and self-testing. In a related vein, Greeno (1980) reported that high school students are typically unable to explain their strategies in solving geometry problems.

<u>Summary</u>. Everything considered, the main implication of recent information-processing research would seem to be the advisability of teaching metacognitive as well as cognitive skills in a skills-instructional curriculum. The argument in favor of explicit teaching of metacognitive skills is an easy one to make: (a) metacognitive skills are important in cognitive performance; (b) students have what seem to be inadequately developed metacognitive skills; and (c) metacognitive skills are not now being taught in most curricula. But there are reasons for being wary of drastic revisions of current educational practices. It is not clear that massive doses of instruction in metacognitive skills is truly what is called for. Consider some reasons why.

1. <u>Large-scale metacognitive training may be impractical</u>. For one thing, we are only beginning to get a glimpse of what metacognitive skills go hand-in-hand with the development of intelligence. For another, those who demonstrate the greatest deficiencies in metacognitive skills (young children and novices of any age at various tasks) seem to have virtually no idea of what they are doing when performing a task. Even when appropriate metacognitive strategies are known, therefore, students may not have the necessary internal referents for the tasks they are working on optimally to take advantage of the metacognitive instruction they receive. Teaching a student to plan is of no help if the student does not know what kinds of strategies can be used in a task.

2. <u>Effects of metacognitive activities may be reduced when they are externally imposed rather than being spontaneously generated by students</u>. There is at least some suggestion that the performance of students using a spontaneously adopted strategy is superior to that of students using a strategy imposed by a teacher or experimenter (Brown, Campione, & Barclay, 1978; Brown & Smiley, 1978).

3. Being aware of the fact that a certain strategy is beneficial is not enough to result in students actually using the strategy. It is one thing to teach students generalized strategies for dealing with problems; it is another to get them to use the strategies. Often, students seem not to use what they are taught (Flavell, 1976; Kreutzer, Leonard, & Flavell, 1975; Moynahan, 1973; Salatas & Flavell, 1976).

4. To be effective, strategies must be so well learned and performed that they do not interfere with actual learning. Rigney (1980) has pointed out that new strategies can actually interfere with performance by taking up resources that otherwise would go to other aspects of problem solving. One characteristic that is commonly attributed to the superior performance of experts over novices is the experts' automatization of control of processing (de Groot, 1966; Rumelhart & Norman, 1976; Simon, 1976). By automatization is meant the transfer of information-processing operations from a limited capacity working memory to a virtually unlimited capacity system that operates without the need for conscious attention. If a new strategy is not automatized, it may take up more mental resources than a student can afford to expend on the strategy.

If metacognitive skills are not now being directly taught, and if there is at least some question as to whether they should be explicitly taught, then one might wonder how they ever could be learned. It is probable that induction from examples plays an important role. Such inductions are simulated by a computer program developed by Williams (1972), the Aptitude Test Taker. This program decides how to solve different types of problems of the sort found on aptitude tests, given only examples of solved problems as a basis for its decisions. A major underlying principle of the program is that the ability to solve a task is largely dependent upon one's ability to induce a solution-strategy from worked out examples (Simon, 1976). Similarly, induction of general properties from examples has been proposed as the means by which strategies for doing geometry problems are learned (Greeno, 1980). An implication of the importance of induction from examples in the development of metacognitive skills is that one might expect an interaction between mental ability and the need to be explicitly taught metacognitive skills. Less able students may not be able to induce effective strategies on their own (see, e.g., Resnick & Glaser, 1976). Others have, in fact, suggested that less able students do better in highly structured learning situations where direct help is given than do more able students (Cronbach & Snow, 1977), for whom less structured situations seem preferable.

In conclusion, the information-processing approach to instruction seems to possess many fertile implications for the improvement of intellectual and knowledge-based skills, as well as for improving direct instruction of curriculum content. But at present, there is a wide gap between theory and practice, and this gap will not be able to be lessened until some of the problematical issues discussed above are dealt with. We are optimistic that the information-processing approach will result in improved instruction, but the fruits of the approach will emerge, we believe, only after extended periods of time whose duration is yet unknown.

Comparison and Evaluation of Perspectives

The similarities and differences among the three approaches to training intellectual and achievement-related skill as well as content knowledge can perhaps best be pointed out by comparing how they would address the problem of training students on a single type of problem. For comparability to our previous section on comparison and evaluation, the type of problem we shall consider is the analogy of the form $A : B :: C : (D_1, D_2)$.

An educator adhering to the psychometric approach would first seek to determine what factors of intellect enter into analogy solution, and then devise a training program around exercises that might raise the individual's standing on these factors. The form the training would take would depend upon the theory.

Spearman's (1927) theory would account for the solution of analogies almost entirely in terms of the "g" (general) factor, which in itself is not particularly helpful in suggesting a training program. Spearman (1923) also proposed an information-processing theory, however, according to which solution of analogies was proposed to require apprehension of experience (encoding the analogy terms), eduction of relations, (inferring the A to B relation), and eduction of correlates (applying the inferred relationship from C to an ideal solution). Thurstone's (1938) theory would probably account for verbal analogy solution in terms of individual differences in the verbal comprehension and reasoning factors, but would not have clear process implications for what should be trained. Guilford's (1967) theory would attempt to train specific cubes of Guilford's model relevant to analogy solution, such as cognition of semantic units, cognition of semantic relations, convergent production of semantic relations, and so on. Note that Guilford's theory handles the process, content, and product with considerable explicitness.

Several general points should be made about the psychometric approach to training. First, unless the theory has a set of process factors (for which Guilford's theory is unique) or is accompanied by a separate information-processing theory (for which Spearman's theory is unique), it is not clear just what one is to train. Second, the decision as to what to train is made on the basis of factors derived from individual-differences data. If there are processes in item solution that are not sources of individual differences, they will not be identified as involved in solution. Third, in most cases the lack of explicit process specification in psychometric theories will result in a rather loose connection between theory and training. As a result, neither success nor failure will necessarily be particularly informative about the value of the theory, if there is an explicit theory underlying the training. Finally, the choice of the analogy in the first place as worthwhile for training will be determined by its centrality in the psychometric theory of intelligence as a marker for one or more factors of intelligence. For example, the analogy would be a good choice of problem to train in Spearman's theory because of its high loading (correlation with) the _g_ factor.

An educator adhering to the Piagetian approach would probably first attempt to determine the child's cognitive level, and to determine whether analogy solution is ready to be accommodated to the child's cognitive structures. If not, the attempt at training might be aborted before it even starts. If the child does appear ready, then the educator might work with the child individually, guiding him or her through the kinds of relations needed to solve the problem. First, the educator would concentrate on pair relations, and once the child seems to understand these, the educator might move on to relations between pairs of pairs. As training proceeded, the educator might more and more play the critic's role, challenging the child in his or her construction or solution of analogies. The point of such criticism would be to bring the child to the point where he or she can solve the item with assurance and lack of hesitation.

Again, several general points should be made about this approach to training. First, the training would almost certainly be preceded by a diagnosis of the child's cognitive state to see whether he or she is ready for training; if not, training would be aborted. In Piagetian theory, there is simply no sense to training a child in skills for which he or she is not yet ready. Second, emphasis in training would be upon logical relations of the kinds specified by Piagetian theory. The goal would not be to train particular processes, but rather understanding of structural relations that constitute an analogy. Third, the mode of training will very likely be individualized, with considerable emphasis on challenge and questioning. The educator wishes to assure that the child truly understands what he or she is doing, and is not just mimicking an algorithm picked up from the trainer. Finally, choice of the analogy item as worthwhile for training will be determined by the centrality of the underlying relations in Piaget's theory. In this case, second-order relations are often used to mark the transition from concrete to formal operations, and thus are viewed as of considerable importance.

An educator adhering to the information-processing approach would first attempt a task analysis of the analogy problem, or use a previously performed task analysis, and only then attempt training on the basis of the task analysis. Depending upon the educator, training might emphasize only the cognitive components involved in analogy solution (for example, encoding, inference, mapping, application, justification, and response, according to Sternberg's, 1977, theory); only the metacognitive components involved in analogy solution (for example, selection of a set of cognitive components, selection of a strategy into which to combine the components, deciding how to represent information about the analogy terms, monitoring one's place in the solution strategy, etc.); or both the cognitive and metacognitive components involved. The educator might attempt to maximize the probability of generalization by concentrating upon information-processing components rather than upon the particular task, and by giving the student practice in solving other kinds of induction problems that involve the same metacognitive and/or cognitive components.

Here as before, several general points should be made about this approach to training. First, the training is preceded by a task analysis, in this case, of an analogy. Note that there is probably a greater emphasis upon the task and a lesser emphasis upon the subject than in the other two approaches. Second, emphasis in the training is upon processing components, whether at the cognitive or metacognitive level, or at both levels. Third, the mode of training will be to emphasize how a set of processes can be combined to solve a problem, of which an analogy is only one example. Good training programs would almost certainly try to show how the same components can be applied to other, related problems as well, so that the student learns to emphasize process generality rather than task specificity in problem solving. Finally, choice of the task will be motivated by the task's centrality in a process-theoretic account of some domain of task performance, in this case, perhaps inductive reasoning. Because analogies are seen as prototypical of induction tasks, their choice would be easily justified.

Our review of the various approaches to training, and of particular studies within each approach, has led us to formulate guidelines that we believe would serve as useful prerequisites for programs of any scale that seek to train intellectual or knowledge-based skills. These guidelines do not constitute a program of training in themselves, but rather what we believe to be necessary conditions for such a program to succeed. The prerequisites we propose, as distilled from our review, are these:

1. The program should specify the information-processing components to be trained, and the components specified should have been experimentally verified as truly involved in task performance. All of the successful training programs seem to have involved process training at some level, and process training can be as good only as the theory upon which it is based.

2. The underlying theory of intellectual performance should be socio-culturally relevant to the individuals who are exposed to the training program based on the theory. We noted in the preceding part of this review that what constitutes environmentally relevant and adaptive performance can differ from one socio-cultural group to another, and even within socio-cultural groups. There is no point to training individuals on tasks that have no relevance or potential relevance to

the individuals' lives. For example, training with a bow-and-arrow might be extremely adaptive in some cultures, and a total waste of time in others. Similarly, for whatever its relevance to various theories of intelligence, analogy training is a sheer luxury for children attempting to survive in an urban ghetto. For whatever good the analogy training may do, it seems almost certain that there are survival skills much more important to these children than the skills involved in solving testlike verbal analogies.

3. The program should provide explicit training in both executive (metacognitive) and nonexecutive (cognitive) information processing, as well as in interactions between the two kinds of processing. If there is one message that comes out clearly from the information-processing literature, it is that durability and transfer of training seem to depend upon a skillful blend of cognitive and metacognitive training. Cognitive training on components of particular tasks is just too specific to result in generalization; but metacognitive training by itself is too abstract and diffuse to result in generalization. A combination of both is needed.

4. The program should be responsive to motivational as well as to intellectual needs of the students it trains. It has become clear that it is not enough to train people what to do--one has to get them to do it, and even more, to want to do it on their own accord. Otherwise, the effects of training can be lost as soon as the child leaves the classroom. A combination of motivational and cognitive interventions seems necessary to insure some degree of generalization outside of classroom situations where the child is on his or her own, without the immediate supervision of the trainer or any other sources of adult authority.

5. The program should be sensitive to individual differences. All of the literature, including the task-oriented information-processing literature, makes clear that children differ both in their rate and style of learning and task performance. A training program that does not take these differences into

account cannot possibly work well for everyone, or even a majority of individuals.

6. The program should furnish links between the training it provides and real-world behavior. Ultimately, it is generalization to real-world tasks that will determine the success or failure of a cognitive training program. But given our knowledge of how difficult it is to obtain transfer even across laboratory tasks, we cannot expect children to make connections between the training they receive and real-world task performance on their own. The program should build in the links, which can then serve as a basis for transfer when the individual encounters related tasks in his or her everyday encounters with the environment.

7. The program should receive careful empirical evaluation, both as a whole and in its facets. It is well known to educators that it is often at least as hard to terminate a program as to initiate it. The investment of time and finances that goes into training programs, not to mention the loss of opportunity to use the time and finances for alternative programs, necessitates a close look at the success of a program, both as a whole and its its facets. Few programs are totally successful: An examination of the aspects of a program will enable the evaluator to determine what aspects of the program have succeeded, what aspects have failed, and what aspects, if any, deserve further development.

In sum, we believe that the theory now exists for forays into the domain of skills training. We also believe that the technology is available for at least modest success in these programs. But we believe the programs will be for nought, as so many past ones have been, unless these prerequisites, at minimum, are taken into account in program formulation and evaluation.

Training Intellectual Skills

If one were to draw any single conclusion from the prerequisites for programs that train intellectual skills listed in the preceding section, it is that there is no one program that works for everyone. As a result, in proposing a training program, it is necessary to specify fairly exactly what one's population is. In our case, we shall propose a training program for intellectually gifted students who are now in or who plan to enter into the mainstream dominant culture in the United States. Although this restriction makes the target domain of our program somewhat limited, we strongly believe that any good program must be so limited. A program that attempts to be everything to everyone will be, on our view, nothing to anyone. Our emphasis on the gifted here is in part a reflection of the task we were assigned by the Commission on Excellence in Education, but also in part a reflection of our own interests. In order to outline the form our proposed program would take, we need first to state what we mean by the "intellectually gifted."

What is Intellectual Giftedness?

We propose that a key psychological basis of intellectual giftedness resides in what might be referred to as "insight skills.' We present here a psychological account of what these insight skills might be. We refer to our account as as "subtheory of intellectual giftedness" in order to emphasize our view that although insight represents an important part of the study of intellectual giftedness, it does not represent the whole story. Certainly other psychological functions--motivation, goal-directedness, logical skills, and so on--constitute other parts of the story as well. We do believe, however, that insight skills form a particularly important part of intellectual giftedness.

Why use the study of insight skills as a preferred entree for studying intellectual giftedness? We believe at least three bases exist for this preference.

First, significant and exceptional intellectual accomplishments--for example, major scientific discoveries, new and important inventions, and new and significant understandings of major literary, philosophical, and similar works--almost always involve major intellectual insights. The thinkers' gifts seem directly to lie in their insight abilities, rather than in their IQ-like abilities or in their mere abilities to process information rapidly. Indeed, it is by now well-known that some major thinkers, such as Einstein and Watson (co-discoverer of DNA), did not test particularly well on IQ tests, for whatever reasons.

Second, exceptional insight abilities are what truly seem to set apart the intellectually gifted from others. Whereas the gifted seem only to differ quantitatively from others in measures of IQ, speed of information processing, ideational fluency (as measured by standard creativity tests), and the like, the gifted seem to differ qualitatively from others in their insight abilities. Whereas the truly gifted may have several or even many major intellectual insights in their lifetimes, the nongifted will probably have no (or very few) major intellectual insights in their lifetimes (as opposed to the relatively more minor kinds of insights that form the bases for term papers, everyday decision making, and the like). Thus, the study of insight seems to form the basis for an understanding of giftedness as a phenomenon in its own right rather than merely as an extension of normal intellectual functioning. If giftedness is simply a quantitative extension of normal intellectual functioning, it is not clear why giftedness should even be studied in its own right rather than as an extension of a general psychology of intelligence, creativity, or other sets of skills.

Finally, it is possible, in studying insight, to get away from the kinds of problems that have so often been used in the past that (a) require large amounts of knowledge, and hence are biased against those with restricted educational opportunities; (b) exercise trivial and uninteresting skills that are of interest only because they are easily measured; (c) emphasize speed rather than exceptional quality of performance; and (d) have no theoretical basis in a psychology of intellectual giftedness (as opposed to only a general psychology of the intellect, or to no theory at all). If one's goal is to avoid pitfalls of past research, insight problems seem at least a good place to start assessment and training.

In conclusion, insight problems seem to provide a theoretically sound basis for understanding intellectual gifted performance. But what insight processes should be trained? And what kinds of supplementary skills need to be trained to maximize the utilization of insight skills?

What is to be Trained?

Insight skills.[2] We believe that insights can be classified as being of three kinds.

1. Selective encoding. An insight of selective encoding involves sifting out of relevant information from irrelevant information. Significant problems generally present one with large amounts of information, only some of which is relevant to problem solution. For example, the facts of a legal case are usually both numerous and confusing. An insightful lawyer must figure out which of the myriad facts confronting him or her are relevant to principles of law. Similarly, a doctor or psychotherapist may be presented with a great volume of information regarding a patient's background and symptoms: An insightful doctor or psychotherapist must sift out those facts that are relevant for diagnosis and treatment. A famous example of what we refer to as an insight of selective encoding is Alexander Fleming's discovery of penicillin. In looking at a petri dish containing a culture that had become moldy, Fleming noticed that bacteria in the vicinity of the mold had been destroyed, presumably by the mold. In essence, Fle-

encoded the information in his visual field in a highly selective way, zeroing in on that part of the field that was relevant to the discovery of the antibiotic.

2. Selective combination. An insight of selective combination involves combining what might originally seem to be isolated pieces of information into a unified whole that may or may not resemble its parts. Whereas selective encoding involves knowing which pieces of information are relevant, selective combination involves knowing how to put together the pieces of information that are relevant. For example, the lawyer must know how the relevant facts of a case fit together to make (or break!) a case. A doctor or psychotherapist must be able to figure out how to combine information about various isolated symptoms to identify a given medical (or psychological) syndrome. A famous example of selective combination is Darwin's formulation of the theory of evolution. It is well known that Darwin had available to him for many years the facts he needed to form the basis for the theory of natural selection. What eluded him for these years was a way to combine these facts into a coherent package.

3. Selective comparison. An insight of selective comparison involves relating newly acquired information to information acquired in the past. Problem solving by analogy, for example, is an instance of selective comparison: One realizes that new information is similar to old information in certain ways (and dissimilar to it in other ways), and uses this information better to understand the new information. For example, an insightful lawyer will relate a current case to past legal precedents; choosing the right precedents is absolutely essential. A doctor or psychotherapist relates the current set of presenting symptoms to previous case histories in his (or her) own or others' past experiences; again, choosing the right precedents is essential. A famous example of an insight of selective comparison is Kekulé's discovery of the structure of the benzene ring. Kekulé dreamed of a snake curling back on itself and catching its tail. When he woke up, he realized that the image of the snake catching its tail was an image of the structure of

the benzene ring.

Metacognitive skills. Insight skills do not, of course, operate in a vacuum. Rather, they are supported by a backdrop of metacognitive skills and knowledge that serve as bases for and facilitators of the insights. We believe that nine metacognitive skills are of central importance to the generation of insightful thinking.

1. Problem identification. The individual recognizes the nature of the problem confronting him or her. For example, in a scientific context, finding a suitable problem to work on is an essential skill.

2. Process selection. The individual selects a set of processes or steps that are appropriate for solving the problem as identified. For example, the individual decides upon the steps needed in order to research the problem he or she has chosen to subject to scientific investigation.

3. Strategy selection. The individual selects a way of combining the processes or steps that have been selected into a workable strategy for problem solution. For example, the individual decides how to sequence the steps of the scientific experiment in a logical order.

4. Representation selection. The individual selects a way of representing information about the problem. For example, the scientific experimenter might choose to draw diagrams, make tables, write an outline, or otherwise represent the experimental design and procedure he or she has chosen.

5. Allocation of resources. The individual decides how to allocate limited resources to the solution of the given problem. For example, the experimenter decides how many observations are needed in the experiment, how much time is required for each observation, what kinds of physical resources will be needed for carrying out the experiment, and so on.

6. Solution monitoring. The individual monitors his or her progress as

the chosen strategy is executed. For example, the experimenter keeps track of how the experiment is going, and if it is not going well, decides what steps to take in order to salvage it, or decides to scrap it altogether.

7. Sensitivity to feedback. The person is aware of and knows how to interpret external feedback regarding the adequacy of his or her chosen strategy. For example, the experimenter is sensitive to feedback from others regarding the adequacy of his or her experimental design.

8. Translation of feedback into an action plan. The individual knows how to use the feedback he or she receives in order to improve the strategy that has been selected. For example, the experimenter uses the feedback he or she receives to modify the experimental design so as to make it better.

9. Implementation of the action plan. The individual acts upon the feedback, implementing the revised action plan. For example, the experimenter actually implements the newly selected experimental design in a revised or augmented experiment.

Cognitive skills. The number of cognitive skills potentially applicable to problems requiring creative insights is undoubtedly extremely large. Nevertheless, our work on inductive thinking has suggested that certain cognitive skills are particularly critical in a variety of tasks requiring insights of one kind of another. We would note here, in particular, five such skills.

1. Inference. The individual discovers one or more relations between two stimulus elements. For example, the experimenter understands how two seemingly discrepant experimental outcomes can be reconciled.

2. Mapping. The individual discovers one or more higher-order relations between two lower-order relations. For example, the experimenter comes to understand how the relation he or she has inferred can be related to relations between experimental outcomes obtained in previous research.

3. Application. The individual carries over a previously inferred relation to a new domain. For example, the experimenter uses the relation he or she has inferred to predict a result in a new experiment.

4. Comparison. The individual compares alternative possible solutions to a problem and decides which is the best from among them. For example, the experimenter decides which of several interpretations of a set of experimental results is most consistent with the present (and possibly past) data.

5. Justification. The individual compares an obtained outcome to an ideally conceived one, and evaluates the degree of difference. For example, the scientist decides whether the outcomes he or she has obtained are sufficiently different from the expected ones to justify rejection of one or more null hypotheses.

Content Vehicles for Training

Our proposed training program would involve training students in these insight, metacognitive, and cognitive skills in three content domains: (a) science (physical and biological); (b) history and government; and (c) literature.

In the scientific domain, students would be in the role of scientists seeking new and significant discoveries. Major discoveries of the past would be presented in case study form, but the scientists' solutions and solution steps would be omitted. Students would be required to design experiments and interpret alternative possible outcomes of the experiments. Thus, they would proceed through the major steps of scientific thinking. The experimental exercises would be graded in difficulty and amount of guidance. In early case studies, students would be presented with relatively easier problems, and would be guided through the uses of the skills described above. As the students proceeded, the cases would become more difficult, and the amounts of guidance would be reduced. Although students would be encouraged to make decisions and evaluations on their own, active group discussion would be a part of the learning process after students had made initial individual efforts. Students would thus learn from each other, as well as from debriefing--after these discussions--of what the scientist dealing with the problem actually did.

In the social-studies (history and government) domain, students would role-play government policy-makers. Major domestic and foreign problems faced by governments in the past and present would be presented in case-study form. Students would be required to decide on what kinds of further information they needed to solve the problems, and then proceed on the basis of the information they have collected. Thus, the students would proceed through the major steps of thinking required of policy-makers. The cases would be graded in difficulty and complexity, and the amount of guidance provided to students would decrease with successive case studies. Again, students would be encouraged to work on their own initially, and then to participate in group discussions led by the teacher. After the discussions had been completed, students would be informed of how the policy-makers had arrived at their own decision, and of what decision they had arrived at.

In the literature domain, students be presented with works of literature for in-depth interpretation. Major works would be presented, and students would be in the role of literary critics having to critique the literary work. Students would be required to decide what aspects of the work to critique, and how to critique it. As in the above instances, passages would be successively graded in difficulty and complexity, and amount of guidance would decrease with successive passages. The same format of individual work followed by group discussion would be used as in the above instances.

We believe that an intensive training program concentrating on insights in three important intellectual domains will help students become aware of and develop their own insight skills. We suggest that many students have such skills, but that they lie dormant as a result of many current curricular practices. Our goal would be to draw out these abilities as much as possible, and then to help students develop them. Although the content domains we have suggested seem particularly susceptible to the kinds of training we have suggested, other domains might be considered as well, depending upon students' interests and needs. Indeed, we believe our theory general enough to support analysis and training in any domain of intellectual endeavor.

One might well ask how our training program would differ from a first-rate course in scientific thought, history, or literature. In our opinion, our program does not differ from such programs at all, except in its cross-disciplinary emphasis and possibly in its concentration upon thought processes rather than the outcomes of these processes. We strongly believe that the best intellectual training is a high-level, rigorous, substantive course in an area of the student's interest. We do not generally favor intelletual skills training programs that concentrate upon developing students' abilities to solve IQ testlike items. Such training seems more geared to tests and testlike criteria used to assess programs than it is geared to developing genuine intellectual skills. Especially for the gifted, if there is one thing we believe they do not need, it is training on IQ test items. Such test items have usually been used to classify the gifted as gifted. But they are not what make the gifted, gifted. No one has ever made a major contribution to society by expertise in solving IQ test problems.

To conclude, we have suggested a theory of what it is that distinguishes the intellectually gifted from the intellectually typical student, and have proposed a broad outline of a training program based on our theory. Although the program has not been implemented or even wholly written, we believe that the program is both theoretically warranted and technically feasible. Moreover, we believe it could be implemented in a way that meets the prerequisites presented earlier. Such a program seems like a fair culmination of the kind of review we have provided in this document. We would hope it capitalizes upon what we have learned about intelligence and its relationship to education, at the same time that it bypasses some of the deficiencies of past approaches.

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Footnotes

[1]This section represents a collaboration between Janet S. Powell and Robert J. Sternberg.

[2]This section represents a collaboration between Janet E. Davidson and Robert J. Sternberg.