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ABSTRACT

The purpose of this paper is to test three hypotheses about background knowledge that arise from the literature of cognitive psychology. The data base consists of the matrices of correlation coefficients that have been accumulated as part of an ongoing meta-analysis of factors influencing attitude and achievement in science. A search of the "Journal of Research in Science Teaching" from 1983-1992 yielded 44 articles which contained a total of 186 usable correlation coefficients. Hypothesis #1 states: A large amount of the variance in measured intelligence results from the effects of background knowledge. This hypothesis was rejected. Hypothesis #2 states: A large amount of the variance in measured cognitive level results from the effects of background knowledge. This hypothesis was accepted. Hypothesis #3 states: A large amount of the variance in measured achievement in science results from the effects of background knowledge. This hypothesis was accepted provisionally, and cnly in the case of procedural knowledge. In summary, the results of the paper indicate that a well-balanced program of science education addressing general intellectual skills, higher order problem solving, and scientific reasoning skills is preferable to one concentrating on background knowledge, and particularly to an over-emphasis on declarative knowledge. (PR)

THREE HYPOTHESES ABOUT DOMAIN SPECIFIC BACKGROUND KNOWLEDGE AND ACHIEVEMENT IN SCIENCE

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from a symposium titled

ENHANCING THINKING SKILLS:
DOMAIN GENERAL VS. DOMAIN SPECIFIC STRATEGIES
A DILEMMA FOR SCIENCE EDUCATION

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Introduction

In convening this symposium, Monsoor Niaz has focused attention on what is emerging as a central issue in science education. To what extent are generalized thinking skills, or scientific reasoning ability, transferable to specific problem solving in science, and how important is the role of background knowledge in achievement in science.

The primacy of the scientific method in science education has been emphasized since at least the time of John Dewey (Archambault, 1964), and very likely well before that. But never was it so atomized as during the process teaching movement that originated in the 1960's. Most prominent, and influential, among examples from that time was Science -- A Process Approach, produced under the aegis of the American Association for the Advancement of Science.

The process/content dichotomy was explicitly stated by Robert Gagne, whose psychological principles were generally taken to provide the underpinnings of that curriculum. While it is academic at this time to dwell upon the intellectual debates among developers of NSF curricula of the 60's, Gagne makes one point that sheds a great deal of light upon the assumptions of that time regarding the expected outcomes of direct teaching of the scientific method to children.

> "In its extreme form, the argument is that there exists in every individual a general trait, creativity, which is subject to improvement through training, and which will when so developed express itself in a variety of fields, including science. The kind of training needed to accomplish this, presumably, is a series of situations in which the individual practices having novel ideas and is rewarded for having them."

(Gagne, 1966)

While denying so extreme a view, Gagne also rejected any "content" approach that entailed the teaching of specific disciplines to children from the beginning school years. Instead, he supported the teaching of "generalizable ideas and skills" and a curriculum that "adopts the idea that productive thinking can be encouraged in relation to each of the processes of science."

For more than two decades since the appearance of such process oriented curricula, there has been a tendency among educators to concentrate on general problem-solving and reasoning skills, under the assumption that these will transfer to specific subject areas. In science education, this trend would be characterized by curricular initiatives such as the scientific literacy course discussed by Baker and Piburn (1990; 1991), whose purpose was to develop scientific reasoning abilities that students could later apply in their subject area science courses. In the more general educational arena, it would be reflective of materials that emphasize direct teaching of thinking as a basic skill (deBono, 1981; Harnadek, 1976; Bransford & Stein, 1984). As a further example, the most recent catalog of Dale Seymour Publications has, in addition to sections on science, mathematics and language arts, one devoted solely to "Thinking Skills".

The emerging literature of cognitive science offers a challenge to such a general approach, and suggests as an alternative that closer attention be paid to the development of domain specific knowledge and skills.

> "A critical theme of the past several years of work in cognitive science has been that a person's intelligent performance is not a matter of disembodied 'processes of thinking' but depends intimately on the kind of knowledge that the person has about the particular situation in question."
>
> Resnick (1983)

Niaz has, I think quite deliberately, imposed a content-process dichotomy upon the structure of this symposium. He has also raised a more fundamental issue regarding older psychologies such as those of Gagne and Piaget, that have guided science education so well, and newer views framed by cognitive psychologists, and especially those working in the areas of Artificial Intelligence and expertise. He cites the contention of Linn that "..researchers from the cognitive science tradition have pushed the pendulum too far in the direction of domain-specific reasoning and that, in fact, domain-general reasoning is an important and frequently overlooked area of investigation" (Niaz, in press). Thus he gives us a challenge that I believe can be met by empirical analysis.

The dichotomy of content and method that has been presented would suggest a crucial test, in which two rival and mutually exclusive hypotheses are placed in competition (Hempel, 1966, pp. 25-28). However, it is my feeling that this dichotomy is false. An alternative, and perhaps more reasonable suggestion is that both are among a variety of factors that contribute significantly to the observed variance in achievement in science, and that the method of regression analysis is better suited to examine the questions that have been raised.

The purpose of this paper is to test three hypotheses about background knowledge that arise from the literature of cognitive psychology. The data base will be matrices of correlation coefficients that have been accumulated as part of an on-going meta-analysis of factors influencing attitude and achievement in science. The method is fully explored in an earlier paper (Piburn, 1992), with extensive commentary (Schach, 1992) and critique (Pigeot, 1992). Copies of these materials can be made available upon request to the reader who wishes more technical detail.

Review of the Literature

In examining factors that influence achievement, it is common to propose two categories. In the first are those thought to be relatively independent of the particular background and experiences of the individual, often thought of as psychological variables. Second are those which may vary independently of the individual's psychological makeup, considered background variables. An issue raised by the current research in cognitive science is the degree to which these two types are actually independent of one another (Yates & Chandler, 1991).

A primary psychological variable, highly correlated with achievement, is intelligence. Despite recent movements to subdivide the intelligence concept, such as the Sternberg's Triarchic Model or Gardner's Multiple Intelligences, Spearman's g (general intelligence) is alive and well. Arthur Jensen, one of the concept's more forceful contemporary advocates, believes that this substrate of intelligence shares more variance with a greater range of cognitive activities than any other single factor (Sternberg, 1990).

Studies in which background knowledge was controlled have shown that the residual variance in achievement resulting from ability differences is not significant (Pearson & Gordon, 1979; Schneider, et al., 1990). This has led to a challenge by cognitive scientists of the nature of the intelligence concept:

> "Differences on cognitive tasks as a function of intelligence can be eliminated or greatly minimized by controlling individual differences in domain-specific knowledge.
>
> (Schneider, 1993, pg. 267)

In this view, "the intelligent mind is viewed as one with a potentially rich supply of pre-existing knowledge" (Yates & Chandler, 1991), and intelligence tests primarily assess background knowledge and the ability to retrieve and apply it in relevant contexts.

It has been well accepted for almost a century that if any two types of ability are factorially distinct from one-another, they are verbal and spatial (Lohman, 1988). Again, however, measures of general intelligence tend to absorb by far the greatest variance in any predictive equation, and the addition of terms for verbal and spatial ability often adds little to its explanatory power.

Superior spatial ability is often assumed to be a characteristic of expert chess players (Chase & Simon, 1973), yet they are not superior to novices on standard spatial measures (Doll & Mayr, 1987). Indeed, Lohman states that conventional "spatial tests add little to the prediction of success in traditional school subjects, even geometry, after general ability has been entered into the regression (1988, pg. 182).

The publication, in 1958, of The Growth of Logical Thinking From Childhood to Adolescence by Barbel Inhelder and Jean Piaget was a significant event for science education. There is no doubt that differences in level of operative reasoning are an important factor in science teaching and learning.

Modern theory in this area is described as neo-Piagetian, and involves an attempt to unify several separate psychological traditions. Science educators involved in this new synthesis have been most influenced by the work of Pascual-Leone (1969), which emphasizes particularly the importance of two performance factors, field effects (perceptual disembedding) and memory capacity (M-demand).

One of the major distinctions between experts and novices is in their memory for relevant information. However, this is exhibited only in relevant contexts. Commonly observed age differences in memory span are reversed when chess is the subject, with young experts displaying greater memory capacity than adult novices (Chi, 1978). This suggests the possibility that "at least part of the developmental change in memory span may be due to children acquiring more domain-specific knowledge" (Mayer, 1987).

Most discussions of memory performance begin with the work of Miller (1957). There is substantial evidence that much of the superior achievement of experts is related to strategies that allow them to cluster information and thus overcome the limitations of short-term memory. It is also apparently true that there are effects of the knowledge base that extend well beyond such strategic competencies, and relate to the way in which information is structured, retained and recalled (Schneider, 1991). When these non-strategic effects are large, the importance of the knowledge base is maximized.

However, not all cognitive psychologists are willing to accept even the neo-Piagetian premise. Some argue that "age-related changes in traits such as perspective taking, classification skills, depth (elaboration) in encoding, memory strategies, operational intelligence, problem solving, verbal facility, and writing facility are attributable directly to growth within the knowledge base" (Yates & Chandler, 1991, pg. 140).

In contrast to these variables, which are psychological in nature, another set can be characterized as reflecting the idiosyncratic background and experience of the individual. These are most commonly associated with schooling, but it is entirely possible that they might be acquired elsewhere.

Interest in such background, or prior knowledge, variables has been generated recently by the research into the development of expertise (Ericsson & Smith, 1991). Of particular relevance to this issue was the contention by Chase and Simon (1973) that the major difference between experts and novices is in their access to relevant domain-specific knowledge.

Relevant prior knowledge is more easily defined in some fields than in others. In the case of chess, used by Chase and

Simon, experts were able to recognize on sight approximately 50,000 chess positions. This is similar to the number of different words that a competent reader of the English language might be able to recognize. However, often also included within this group of acquired knowledge bases are information processing, problem solving, or meta-cognitive strategies that are not thought of as psychologically innate (Ericsson & Smith, 1991).

A common distinction is often made between declarative (sometimes called propositional or semantic) and procedural (sometimes called algorithmic) knowledge (Schuell, 1985; Stahl, 1992; Yates & Chandler, 1991). Among the first are such variables as prior course-taking experience and general knowledge as assessed by achievement tests. One should not, however conclude that declarative knowledge is necessary static nor primarily factual. A more important characteristic of expert knowledge bases was that they were not only more extensive, but that they contained concepts that were more differentiated and inter-related (Gobbo & Chi, 1986). Nor should one conclude that procedural knowledge consists predominantly of poorly understood algorithms for problem-solving. Included in this latter category are a variety of measures of creativity, productive thinking and scientific reasoning. Measures of both declarative and procedural knowledge have been shown to be predictive of success in science.

To summarize, the literature of science education has, until quite recently, focused almost exclusively on psychological characteristics. From among these, spatial ability, memory capacity and operational level have emerged as significant predictors of variance in achievement. More recent advances in cognitive psychology have challenged the assumption that these are orthogonal to background factors. Instead, exceptional memory or spatial ability are displayed by experts only in extremely context-specific situations, and differences in performance on cognitive tasks can be eliminated by controlling for domain-specific knowledge (Schneider, 1993).

One might conclude from such a review that it is at least a tenable hypothesis that existing knowledge is one of the most powerful factors to be taken into consideration when considering the education of people in science.

Statement of the Problem

Two positions have been outlined above. The first is that psychological variables that are predictive of success in science operate relatively independently of background variables. The second is that differences in achievement are largely related to individual differences in domain-specific knowledge. A test of these will be conducted by estimating the variance in achievement in science that is associated with psychological and background variables.

Three sets of independent variables have been chosen for this test. The first set are characterized as intelligence measures, and include verbal, spatial and general intelligence. The second are neo-Piagetian measures, and include field dependence-independence, memory capacity and cognitive level. The third are the background variables of declarative and procedural knowledge. The dependent variable is achievement in science.

Three specific hypotheses derived from the literature of cognitive science will be presented for testing in a later section of this paper.

Method

The procedure of meta-analysis was suggested by Glass (1976) as an alternative to other methods then in use for the review of prior research. It is a powerful means of aggregating quantitative results across a large number of research reports, and has commonly been used in summarizing the results of experimental studies. Less commonly, meta-analysis has been used to compare the results of correlational studies.

While a variety of procedures are available for weighting the values of correlation coefficients from different studies (Hedges & Olkin, 1985; Schmid, Koch, & LaVange, 1991), these have not been used in the few studies of this type to be found in the science education literature. Instead, the procedure of choice has been to collect a pool of similar correlation coefficients and to report their means and variances.

The technique used in this study is regression analysis. Hypothesis testing is conducted by varying the order of entry of independent variables into the regression equation. This follows the injunction by Kerlinger that, since order of entry has a profound impact on increase in variance explained at each step, "order of entry of independent variables into the regression is determined by the research problem and the design of the research" (1973, pg. 628). Interpretation may also be based upon the values of Beta. These are the standardized regression coefficients, whose magnitude is independent of the order of entry. They can be thought of as equivalent to simple correlations between two variables (Nie, Hull, Jenkins, Steinbrenner & Bent, 1975, pg. 325). Under normal circumstances, Beta coefficients are subject to the same type of significance testing as correlation coefficients. However, this does not appear to be so easy in a meta-analysis, where the correlation coefficients used in the regression are not associated with any sample size.

All issues of the Journal of Research in Science Teaching from 1983 through 1992 were reviewed. In most cases, correlation coefficients were extracted directly from the article. However, it was occasionally necessary to record a regression coefficient instead. Such coefficients "can be interpreted much like an ordinary coefficient of correlation" (Kerlinger, 1973. pg. 621). In a few studies an unusually large number of similar correlations were recorded, as for example the relationship between a variable and 3-5 separate examination scores in several different courses. Where it seemed suitable, a single average was computed and recorded.

This search yielded 44 articles which contained a total of 186 usable correlation coefficients. These were grouped into 37 different categories, and summary statistics were computed for each.

From among these, eight represented relationships between achievement in science and other variables (Table 1).

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Table 1. Mean correlations between scientific achievement and background variables

ACHIEVEMENT IN SCIENCE	MEAN CORRELATION	STANDARD DEVIATION	NUMBER OF STUDIES
x Verbal ability	.40	.25	4
x Spatial ability	.41	.22	5
x General ability	.41	.22	5
x FDI	.29	.18	13
x Mental capacity	.21	.20	8
x Cognitive level	.44	.15	15
x Procedural knowledge	.40	.16	6
x Propositional knowledge	.39	.12	8

****

Six psychological variables were chosen. These were general intelligence, verbal and spatial reasoning, field dependence-independence, mental capacity, and cognitive ability. These were organized into two groups on the basis of a priori theoretical constructs; intelligence and neo-Piagetian.

Two general categories of background or prior knowledge were aggregated; procedural and declarative. Procedural knowledge consisted of measures of scientific and quantitative reasoning. Declarative knowledge included variables which, in the original study, had been characterized as measuring prior knowledge. This last group ranged widely, including pre-tests, standardized achievement tests, prior course work, and Grade Point Average.

The Hypotheses

HYPOTHESIS #1: A LARGE AMOUNT OF THE VARIANCE IN MEASURED INTELLIGENCE RESULTS FROM THE EFFECTS OF BACKGROUND KNOWLEDGE.

Although ardent advocates of the concept of a unitary variable that captures most of the variation in human abilities are alive and well, the concept itself is under serious attack. Resembling in form, although not content, the factorial model of Guilford (1967), are two prominent and influential recent descriptions of intelligence.

Verbal and spatial ability are among the seven intelligences proposed by Gardner (1983). However, he emphasized that these are not to be found in psychological tests. Rather, they should be sought in the context of practice. Intelligences are to be known though the existence of experts, prodigies, and cultures which identify and nurture such talents.

Another view of intelligence is that it is, in part, the ability to acquire knowledge (Sternberg, 1985). Thus, a strong knowledge base gives evidence of intelligence. Perhaps the most extreme position in this regard is that "measured IQ is a proxy variable representing, in large part, the individual's existing knowledge" (Yates & Chandler, 1991).

From this perspective , one would predict that the variance in intelligence would be shared with several more basic factors, and that prior knowledge would be prominent among these.

Intelligence and general ability measures collected in this study included were the abstract reasoning sub-test of the Differential Aptitude Test (DAT), the Primary Mental Abilities Test, Raven Progressive Matrices, the School and College Abilities Test, and the Otis-Lennon Intelligence Test.

The most commonly accepted primary components of spatial ability are visualization and spatial orientation (Ekstrom, French, Harman & Dermen, 1976). Three of the five relationships found for this study were with spatial rotations. The remaining two were between achievement and the spatial and mechanical reasoning sub-tests of the Differential Aptitude Test (DAT).

Verbal abilities were measured in four studies, and their correlation with achievement computed. The measures used were the vocabulary sub-test of the Stanford Achievement Test, the verbal sub-test of the Cognitive Abilities Test and the Descriptive Test for Language Skills. Although none are counted among the more traditional measures of verbal ability, they seem suitable for the purpose addressed in this study.

The more familiar measures of procedural knowledge are process measures such as the Test of Integrated Process Skills (TIPS) or the Process of Biological Investigations Test. Such types of measure have more often been used as dependent than as independent variables in science education research. However, it is at least as reasonable to think of them as measures of generalized procedural knowledge that would be useful in promoting achievement.

Four types of declarative knowledge variables were identified in this study. The first are standardized assessments of achievement in science, such as the California Achievement Test or College Board examinations. The second are pre-tests, sometimes taken from item banks and often similar or identical to the post-test used in the same study. Third are the number or type of misconceptions held by students. Finally are in earlier course work, as for example science grade-point average.

The first hypothesis was tested by regressing Intelligence first against prior knowledge, propositional and procedural, and

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Table 2. Regression of intelligence against prior knowledge, verbal and spatial ability

DEPENDENT VARIABLE = GENERAL ABILITY

Independent Variable	Multiple r	Multiple r-squared	Beta
Declarative knowledge	.54	.292	.092
Procedural knowledge	.57	.328	.028
Verbal ability	.77	.595	.594
Spatial ability	.80	.640	.267

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then following these with verbal and spatial ability, in that order. The results are given in Table 3.

Although the initial correlations between background knowledge and intelligence are high, they by no means capture the full variance in that latter variable. Addition of verbal and then spatial ability to the equation doubles the explained variance in intelligence, from 32% to 64% The values of Beta tell a similar story. The highest value is for verbal ability, followed by spatial ability. The Betas for prior knowledge are close to zero. When the variance shared with verbal and spatial reasoning is eliminated, prior knowledge no longer predicts any variance in intelligence.

The first hypothesis is rejected.

HYPOTHESIS #2: A LARGE AMOUNT OF THE VARIANCE IN MEASURED COGNITIVE LEVEL RESULTS FROM THE EFFECTS OF BACKGROUND KNOWLEDGE.

The most prominent recent tradition in science education has been within the Piagetian framework, which posits, above all other hypotheses, the existence of invariant developmental sequences that characterize human thought. This has been a truly productive line of inquiry, with broad explanatory and predictive capabilities. However, even with the sophistication added by the neo-Piagetian school, this line of inquiry has been increasingly unable to account for the unique performances that are now being described on the part of experts across many fields.

Science educators have been especially attracted to two neo-Piagetian variables thought to underly operational thought. These are memory span and field effects (Pascual-Leone, 1969). Both have been shown to be predictive of success in science.

Expertise seems to confound all known rules about memory. Experts remember more than predicted, but only in their field of expertise, and normal developmental sequences are reversed when the experts are children and the novices adult. With specific regard for memory, the hypothesis is that experts have both conceptual networks and chunking strategies, both forms of prior knowledge, that allow superior memory performance.

There is strong support among cognitive theorists for a position that developmental trends in reasoning ability may also be attributed to the accumulation of knowledge. An example is horse punters (betters), whose years of experience seems more important to their success than any measure of intellectual or cognitive ability. Cognitive performance of all types is facilitated by a well prepared mind, and it is difficult to demonstrate ability in any area about which you know little.

Mental capacity is most often measured by means of digit span tests, in which a subject is asked to repeat strings of letters or numbers. However, Burtis and Pascual-Leone created a measured called the Figural Intersection Test specifically to measure M-space.

The literature on expertise does not address the question of Field Dependence-Independence. However, one would anticipate that, just as is the case of spatial ability, performance would depend crucially upon the context within which it is displayed.

Although the concept of field-ground is an old one in psychology, the field effects emphasized in Pascual-Leone's theory refer more specifically to the phenomenon of field-dependence/independence (FDI) formulated by Witkin (Witkin, Dyk, Faterson, Goodenough & Karp, 1962). Witkin's original work, conducted with subjects in an inclined room, characterized people on a continuum from those who were influenced most heavily by internal (the force of gravity) to external (the room, or field) cues. Those latter individuals were called field-dependent. Subsequently, Witkin turned to the Embedded Figures Test to measure this same quality, which he then called restructuring. Those subjects who were unable to restructure were unsuccessful on the Embedded Figures Test and were thus field-dependent.

The Embedded Figures Test is similar to the Hidden Figures Test, which itself is an adaptation of the older Gottschaldt Figures test popularized by Thurstone (Ekstrom, French, Harman & Dermen, 1976). Both of these latter instruments are traditionally considered to be measures of flexibility of closure, which some authors consider to be an element of spatial ability and others contend is related to the ability to break set (Lohman, 1988).

Measures of cognitive ability included the Developing Cognitive Abilities Test, the Group Assessment of Logical Thinking, several forms of the Lawson Test of Formal Reasoning, the Propositional Logic Test, the Test of Logical Thinking, and a variety of clinical Piagetian measures.

The question of whether or not background knowledge contributes significantly to measured cognitive ability, and what further contribution might be attributed to Field Dependence-

Independence and memory span, was addressed by regressing cognitive ability against those other factors (Table 4).

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Table 3. Regression of cognitive level against background knowledge and neo-Piagetian variables.

DEPENDENT VARIABLE = COGNITIVE LEVEL

Independent Variable	Multiple r	Multiple r-squared	Beta
Declarative knowledge	.57	.325	.380
Procedural knowledge	.59	.349	.184
FDI	.61	.374	.171
Memory span	.61	.376	.063

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The results indicate that single greatest contribution among these variables to the observed variance in operative level is that of prior knowledge, and particularly propositional knowledge. The Beta for the latter variable is more than twice as large as the next largest, and 35% of the variance in operative level can be explained as the result of prior knowledge. Field Dependence-Independence contributes approximately the same variance as procedural knowledge, but memory span vanishes from the equation.

Almost 35% of the variance in cognitive level appears to result from background knowledge.

The second hypothesis is accepted.

HYPOTHESIS #3: A LARGE AMOUNT OF THE VARIANCE IN MEASURED ACHIEVEMENT IN SCIENCE RESULTS FROM THE EFFECTS OF BACKGROUND KNOWLEDGE

Intelligence and cognitive ability are usually thought of as independent factors in achievement, and often load on separate factors during factor analysis. Thus, it is reasonable that they both be included in such an analysis.

Most authors in cognitive science agree that "superior performance in different domains reflects processes and knowledge specific to the particular domain" (Ericsson & Smith, 1991, pg. 26). In fact, it is widely hypothesized that background knowledge is the single most important factor in learning. Thus, measures of declarative and procedural knowledge might be expected to share a large amount of the variance in achievement.

Measures of background knowledge, intelligence and cognitive ability have already been described. Achievement measures included test and examination grades, gain scores from pre- to post-test, course grades, grade point average, and achievement on standardized tests.

This last hypothesis was tested by regressing achievement against background knowledge, followed by intelligence and then

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Table 4. Regression of achievement against intelligence, cognitive level, and background knowledge

DEPENDENT VARIABLE = ACHIEVEMENT

Independent Variable	Multiple r	Multiple r-squared	Beta
Declarative knowledge	.40	.160	.071
Procedural knowledge	.47	.223	.189
Intelligence	.51	.255	.202
Cognitive level	.54	.296	.253

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cognitive ability (Table 4). In this analysis, background knowledge captures some, but by no means all, of the variance in achievement. Entry of intelligence and cognitive level increased the explained variance from 22% to 30% More telling are the

Betas, which show that cognitive level, intelligence, and procedural knowledge occur in that order of importance. The relative contribution of declarative knowledge to achievement is small.

The third hypothesis is accepted provisionally, and only in the case of procedural knowledge.

DISCUSSION

An initial surprise resulting from the test of these hypotheses is the robust contribution of verbal and spatial ability to measured intelligence.

No one would argue against the significance of verbal skills in our world and, indeed, verbal ability is one of Gardner's seven intelligences. In evidence, he cites a number of societies within which the development of rhetorical skills and public speaking are important prerequisites to positions of prestige.

There is less discussion in the literature on expertise about the role of spatial ability. The exception seems to be chess, where "superior spatial ability often is assumed to be essential" (Ericsson & Smith, pg. 6). One set of results linking chess masters to superior ability in memory tests involving the position of chess pieces indicated that a factor in their performance might be superior visual memory. Using his expertise criterion, Gardner includes spatial ability as an intelligence on the basis of evidence of cultures where children are screened for exceptional spatial ability and subsequently trained for specific roles, such as navigator, in their culture.

Although spatial skills are rarely part of the curriculum, there is extensive evidence that they have an claim equal to that of verbal skills for our attention. Research in science education demonstrates that they can be quite successfully taught (Lord, 1985, 1987), and such instruction has been shown to improve conservation task performance for young children (Dolecki, 1981) and physics achievement for college students (Pallrand & Seeber, 1984).

A second surprise is the failure of background knowledge to predict measured intelligence. While this may be an artifact of the specialized nature of the knowledge variables accumulated in this study, it still refutes most of the major assumptions of cognitive scientists about the intelligence concept.

Studies of expertise have demonstrated the importance of memory in performance as diverse as that of bartenders and chess masters. Yet this variable did not emerge here as an important one. This suggests that cognitive scientists are quite correct in their assertion that improved memory performance is largely attributable to prior knowledge.

The characterization of background knowledge in this study uses the same distinction that is implicit in the dichotomy of declarative and procedural. In the first category are those measures that include standardized achievement test scores, pre-tests on curriculum relevant items, or prior achievement in science. Procedural knowledge is most commonly characterized as scientific process skill. The analyses presented in this paper demonstrate the independent and important contributions of both declarative and procedural knowledge in predicting cognitive ability.

The relative importance of background knowledge to achievement is diminished somewhat when its contribution is compared to that of intelligence and cognitive ability. In addition, only procedural knowledge seems important in this analysis.

These results support a model for the development of scientific achievement that varies somewhat from the contemporary view of cognitive scientists, and is not unlike the one that is currently in place in science education. Despite the contention that intelligence is largely a prior knowledge variable, most of the variance in general intelligence in this study appears to be captured in verbal and spatial skills. While it is true that background knowledge contributes to cognitive ability, a large amount of variance in the latter remains unexplained. Finally, psychological variables emerge as much more powerful predictors of achievement in science than would have been predicted from the perspective of cognitive science.

Implications

These results have special meaning to the question raised by this symposium. It appears that domain-general teaching may have the desired consequence of improving performance in science classes, and that an extreme focus on domain-specific content may not be warranted.

It is particularly apparent that emphasis on general verbal and spatial skills, as well as other "intelligences" contained within the Gardner model, may be warranted. Although spatial skills are rarely part of the curriculum, they can be quite successfully taught (Lord, 1985, 1987), and such instruction has been shown to improve conservation task performance for young children (Dolecki, 1981) and physics achievement for college students (Pallrand & Seeber, 1984). There is very definite reason to believe that better spatial skills result in improved performance in science, and that the results can be educationally meaningful.

An emphasis on scientific reasoning is definitely supported, with attention both to procedural knowledge and more general cognitive skills. Developing a wide fund of declarative knowledge does not seem so important, although there is some evidence that it may help students to develop reasoning abilities.

The issue is well illustrated by an example cited by Niaz. When presented with a "Trees Puzzle", there was a very significant age-related trend in the ability of children to raise causal questions. From the Piagetian point of view, these data would suggest an increasing level of cognitive development accompanied by "the scientific thinking skills of raising causal questions, generating hypotheses and conducting experiments" (Niaz, in press). An equally plausible alternative hypothesis is that you have to know something about trees in order to raise questions about them, and that the observed improvement in complex reasoning is at least in part related to a greater fund of stored experience. The results of the analyses presented here would seem to support such an interpretation.

In summary, the results of this paper indicate that a well-balanced program of science education addressing general intellectual skills, higher order problem solving and scientific reasoning skills is preferable to an one concentrating on background knowledge, and particularly to an over-emphasis on declarative knowledge.

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