Ability Testing

PS *examines the state of theory and some current trends in ability testing*

General Article

COGNITIVE ABILITIES: The State of the Art

By John B. Carroll

An important paradigm in psychological science concerns the sources, measurements, and dimensions of individual differences in cognitive abilities, as well as issues pertaining to their development, consistency, and malleability The paradigm's history can be traced back for more than a century, at least to Francis Galton and James McKeen Cattell Problems of measurement have been identified with such names as Alfred Binet, Lewis Terman, and David Wechsler Dimensional analysis has been the concern of Charles Spearman, Cyril Burt, L L Thurstone, J P Guilford, R B Cattell, and many others Issues of the sources, consistency, and malleability of individual differences have been addressed by such figures as E L Thorndike, Barbara Burks, Marie Skodak, and Harold Skeels

The paradigm has for various reasons never been considered to be central to the science, and until recently it has seldom been pursued with any vigor by experimentalists (Hunt, 1987) There have been difficulties in relating it to learning, memory, perception, motivation, and other topics of interest in theoretical psychology (Estes, 1982) A recent report on the achievements of behavioral science (National Research Council, 1988) gave it scant attention as a field that needed support and further development Many of the problems with which differential psychologists have concerned themselves—for example, the measurement of aptitudes and achievements, the methodology of factor analysis, and the assessment of genetic and environmental influences—have led to seemingly intractable controversies

What is more, some of these controversies have had parallels in important social issues Plomin, DeFries, and McClearn (1990) remarked that "societally relevant issues in the behavioral sciences are usually issues of individual differences" (p 6) Snyderman and Rothman (1988) compared views of prominent individual difference psychologists with those allegedly promoted or emphasized in the media—press and television They found that most of the psychologists they surveyed attached high value to the concept of intelligence, affirming that it can be accurately measured and that genetic endowment plays a substantial role in it In contrast, according to them, the media have falsely created the impression that the majority of concerned specialists downplay or even deny the role of genetic factors in IQ As Snyderman and Rothman noted, "The key to understanding the IQ controversy lies in the historical conflict between two schools of American thought, the desire for increasingly efficient and objective assessment, and the belief in human equipotentiality" (p 11) They pointed out that "while the news media did not create the issues of the nature of intelligence, IQ heritability, and racial differences in test scores, they have, by the nature of their coverage, contributed significantly to the propagation of the public controversy surrounding these issues" (p 183) Yet in a review, Lennon (1990) called Snyderman and Rothman's work "insensitive, irresponsible, and dangerous" (p 213) There still exists, and will probably continue to exist, a substantial segment of public and even professional opinion that believes either that individual differences in cognitive abilities are illusory, insubstantial, or superficial or that such differences are totally explicable in terms of learning, culture, and other environmental influences

As one who has long been concerned with the dimensional analysis of cognitive abilities, I am moved to offer a personal perspective on the present state of the field, its

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current directions, and needs for research and development

There can be no doubt that, over the past decade, the field has entered a phase of greatly increased activity The journal *Intelligence* is already in its 16th year of publication Numerous other journals, as well as a series of collections edited by Sternberg (1982–1989), carry relevant materials Two voluminous handbooks (Sternberg, 1982, Wolman, 1985) offer encyclopedic treatments of major issues, and new theories of intelligence have been presented (Anderson, 1992, Gardner, 1983, Sternberg, 1985, 1990)

MEASUREMENTS OF COGNITIVE ABILITIES

On the one hand, revisions and new versions of traditional intelligence measures continue to appear, paying at least lip service to new developments in the theory of such measures—for example, the WISC-III (a third edition of the Wechsler Intelligence Scale for Children, Wechsler, 1991) and the K-ABC (Kaufman Ability Battery for Children, Kaufman & Kaufman, 1982) In offering Verbal, Performance, and Full IQ scales, the WISC-III carries forward the structure of abilities defined in previous versions (see a review by Carroll, in press-b), the K-ABC incorporates ideas from Luria's theory of simultaneous and successive processing (see Das, Kirby, & Jarman, 1979) Jackson's (1984) Multidimensional Aptitude Battery is essentially a group-test, paper-and-pencil version of the WAIS (Wechsler Adult Intelligence Scale) One of the most widely administered group tests of cognitive abilities is the Armed Services Vocational Aptitude Battery (ASVAB), used in diagnosing abilities of potential U S defense forces recruits, carefully honed for this purpose over a period of years (Foley & Rucker, 1989) All these batteries feature dimensions of intelligence such as verbal, reasoning, spatial, quantitative, and memory abilities that have been recognized, for at least 50 years, as being partly independent traits, along with a more global trait of general intelligence A complaint sometimes heard is that the technology of intelligence testing offers little in the way of novelty over procedures developed in the early years of the century Nevertheless, in a sense these procedures are "tried and true", they need only minor refinements and adjustments to keep them up to date with changing populations, cultural circumstances, and technical developments in test construction and analysis

On the other hand, discussions and debate over the nature of intelligence and cognitive abilities have caused researchers to explore these abilities in terms of categories of knowledge and process studied in cognitive psychology The very notion of ability has undergone change as a result of the development of new psychometric models An ability is seen as a latent trait or characteristic of individuals that expresses itself in differential performances on a class of tasks that vary in their demands (generally, their difficulty or their timed nature) as a function of defined task attributes Establishing an ability, or a measure of that ability, is therefore in the first instance a problem of determining what kinds of tasks, and what attributes of those tasks, should be involved in its measurement It is also a problem of determining whether the measure has desirable characteristics, for example, high homogeneity and reliability, according to the psychometric model Consideration of task attributes leads to more precise definition of the ability by placing the ability within a specified domain of tasks

As yet, few of the traditionally recognized abilities have been subjected to this kind of analysis, but examples can be cited Pellegrino, Mumaw, and Shute (1985) investigated the spatial reasoning ability measured by form board tasks—the type of task in which the subject, presented with a collection of spatial forms, is asked to decide which of several choices shows these pieces correctly put together to form, say, a square Pellegrino et al showed that a model that considered such task attributes as the number of pieces, the number of spatially displaced pieces, and the number of pieces that had to be rotated accurately predicted item performance statistics on processing speed and accuracy Similarly, Butterfield, Nielsen, Tangen, and Richardson (1985) tested a theoretical model that fairly well predicted, on the basis of task characteristics, the difficulty of letter-series reasoning tasks of the kind frequently found in intelligence tests

An example of a psychometric investigation that employed concepts from cognitive psychology is Kyllonen and Christal's (1990) study of the role of working memory, as conceived by Baddeley (1986), in performance on various types of reasoning ability tests Working memory was found to be highly correlated with processing speeds on such tests, but estimates of general knowledge (declarative memory) also made a contribution to performance This study is one of a series in which Kyllonen, Christal, and their colleagues are attempting to establish a firm basis for interpreting individual differences in learning rates on various tasks (Kyllonen & Christal, 1989)

THE STRUCTURE OF COGNITIVE ABILITIES

The methodology of choice in studying the structure of cognitive abilities has been factor analysis, based, ideally, on correlations among carefully defined and experimentally differentiated ability measurements Although it has sometimes been fashionable to criticize factor analysis as being a technique with many problems—for example, the problem of the number of factors to extract,

the problem of whether principal components or principal factors should be extracted (Velicer & Jackson, 1990), and the problem of indeterminate rotations to simple structure—I am persuaded that these problems can be and have been satisfactorily resolved to the point that at least for well-designed sets of variables, reasonable and replicable solutions can confidently be arrived at (Carroll, 1985) Factorial methodology now has two main variants *exploratory* factor analysis as developed by Spearman, Thurstone, and many others, and *confirmatory* factor analysis, developed chiefly by Joreskog (1978) as a special case of structural equation modeling and hypothesis testing While these variant methodologies continue to present special problems, sufficient agreement has been reached to permit them to converge on similar conclusions about the dimensions and structure of cognitive abilities

I have undertaken a survey of the factor-analytic literature, reanalyzing (with exploratory techniques) some 460 data sets culled from that literature From this survey, I have concluded that the structure of abilities can best be described in terms of a three-stratum model comprising a single *g* factor at the apex, or third stratum, a series of broad abilities at the second stratum (many of which had been identified by Hakstian & Cattell, 1978), and a larger set of narrow abilities (such as lexical knowledge, phonological ability, visualization ability, and various types of reaction time abilities) at the lowest stratum (Carroll, 1989, in press-a) Using confirmatory factor analysis, Gustafsson (1984, 1989, Undheim & Gustafsson, 1987) arrived at a similar three-stratum model, arguing, however, that the general factor at the third stratum is equivalent to a second-stratum fluid ability factor It is to be noted that both exploratory and confirmatory techniques can be formulated in such a way as to produce information on a series of orthogonal factors at different orders of analysis In exploratory analysis, I have preferred to use Schmid and Leiman's (1957) transformation for this purpose, in his confirmatory analyses, Gustafsson uses a model calling for orthogonal factors The two methods tend to produce approximately similar results when applied to a given set of data

As yet, I have been able to arrive at only an incomplete and imperfect depiction of the total domain of cognitive abilities because the data sets on which it is based exhibit great variation in the variables studied, and these variables are often insufficiently refined and differentiated I stress, in particular, that conventional measures of cognitive abilities—even those contained in a widely used kit of factor-reference measures (Ekstrom, French, & Harman, 1976)—do not adequately permit differentiation of difficulty level and speeded aspects of ability There is still much work to be done in test design (Embretson, 1985) and factor analysis The lack of sufficient knowledge about the variety and structure of cognitive abilities is a hindrance to the development of an adequate theory of cognitive abilities and to the construction of satisfactory and comprehensive measures of these abilities

The construction of a theory of cognitive abilities is relevant to the issue of the extent to which the validity of cognitive tests in predicting school or occupational success can be attributed to the operation of a general factor of intelligence (See, e g , a series of papers, edited by Gottfredson, 1986, that consider the idea that the general factor is the most important variable in predicting occupational success) Many reports of factorial studies contain statements to the effect that the general factor contributes the largest amount of variance, say, 90%, to a test battery This statistic is misleading It can be shown that the proportion of variance that the general factor contributes to a particular measurement is often much less, perhaps no more than 50% on the average This leaves the possibility that narrower ability factors can contribute appreciable proportions of variance to particular variables in a factor analysis, and that such factors can be important in predicting external criteria

DEVELOPMENTAL ISSUES

Most of our information about the growth, development, and possible decline (with aging) of cognitive abilities is based on studies using global measures such as mental age and IQ, or the verbal and performance scales of the Wechsler measures We have relatively little knowledge of detailed developments of specific mental abilities during the period from infancy to adulthood There have been interesting results concerning differential declines with aging with respect to broad abilities such as fluid and crystallized intelligence (Horn, 1982), but these findings need to be greatly extended through consideration of the range of broad and narrow abilities

Historically, there has been interest in the possibility that abilities become more differentiated with age In my survey, I have found little evidence of age differentiation over the developmental period, except possibly in the language ability domain, where special abilities can emerge through exposure to printed language I have been impressed with the fact that a wide range of abilities can appear at almost any age For example, various types of reasoning ability appear from quite young ages There is still a question of whether an ability measured at age 8, say, is the same kind of ability when measured at age 21 Detailed studies of growth in different kinds of ability are needed

NATURE AND NURTURE ISSUES

Individual differences in cognitive abilities have generally proved to be surprisingly consistent and resistant

to modification by various types of training, family placements, and other interventions (Detterman & Sternberg, 1982, Spitz, 1986) There is general agreement among behavioral geneticists (Plomin et al , 1990) that a considerable portion (probably at least 50%) of the variance in traditional cognitive ability measurements such as IQ is genetic in origin Several recent studies (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990, DeFries, Olson, Pennington, & Smith, 1991, Vernon, 1989) have suggested that genetic variance is also present in certain special abilities Studies in behavioral genetics have not yet had an opportunity to take full advantage of new knowledge on the structure of cognitive abilities, largely because of the difficult logistics of conducting appropriate studies (longitudinal, twin, adoption, etc) and the fact that appropriate measurements and methods of statistical analysis have only recently become available Even studies using a number of different kinds of measures to assess the heritability of special aptitudes have not adequately controlled for the possibility that measures of such special aptitudes include a considerable amount of variance due to a general factor

More generally, we do not yet have adequate knowledge of what aspects of cognitive ability can be readily modified and what aspects are more resistant to such modification Certainly there is need for such knowledge—knowledge that would help specify the limits to which particular abilities can be enhanced, and the conditions under which such enhancement could occur To the extent that basic cognitive abilities may govern how much school achievements can be promoted over the school years, such knowledge could have important policy implications Also, there are large classes of ability (e g , productive and creative abilities) about which next to nothing is known in regard to genetic and environmental influences A work by Howe (1990) is illustrative of a widespread point of view that exceptional abilities are in the main the result of special effort and environmental influences, but this work seems to neglect a considerable amount of evidence that there are individual differences in potential

USES OF COGNITIVE ABILITY TESTS

Despite numerous questions that have been raised about, for example, their validity, freedom from bias, and social costs, cognitive ability tests continue to be used in a great variety of contexts In my view, use of cognitive ability tests must be informed by knowledge of what kinds of abilities are involved and what kinds of tasks they pertain to The advances in the analysis of cognitive abilities that I have described should increasingly enhance success in the application of cognitive ability tests For example, the analysis of reading disabilities can profit from new knowledge concerning the dimensions of abilities in various reading tasks (Frederiksen, 1982, Stanovich, Cunningham, & Feeman, 1984) An interesting and promising development in the use of cognitive ability tests in industrial selection is the work of Fleishman and Reilly (1992, see also Fleishman & Quaintance, 1984) in producing a handbook of cognitive abilities tied to an analysis of job tasks for which they are presumably appropriate This work needs, of course, to be followed up by further validity studies

FINAL COMMENT

Space limitations preclude discussion of numerous problems incident to the notion of cognitive ability for example, the degree to which cognitive abilities are unitary and homogeneous across individuals, the role of specific strategies in performing cognitive tasks and their relation to putative unitary, homogeneous abilities, and the problem of units of measurement All these, and undoubtedly many other problems, must be addressed in further studies in what I judge to be an exciting and highly promising renascent field

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