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Information Processing and Intelligence

Where We Are and Where We Are Going

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INTRODUCTION

Intelligence tests are about one hundred years old. If you agree with Boring (1923) that intelligence is what the intelligence tests measure, then the science of intelligence is one hundred years old. I will call this *psychometrically defined intelligence*. Empirically the study of psychometric intelligence is a booming field, for it has led to a very large literature, impressive technological developments, and coherent relationships among test scores (Carroll, 1993). However, it has a weakness.

A purely psychometric approach to intelligence lets the technology of measurement define the concept, rather than the concept defining an appropriate measurement technology. Along with many others, I prefer a more conceptual, less boring approach. The conceptual definition of intelligence as individual variation in mental competence has a longer history. In the sixteenth century the Spanish philosopher Juan Huarte de San Juan (Huarte, 1575/1991) proposed a multifaceted theory of intelligence that was not too far from today's crystallized–fluid distinction. In the nineteenth century, Galton (1883) used laboratory techniques for measuring individual differences in basic mental processes that are recognizable ancestors of paradigms used in today's laboratories. And for that matter, Binet, the founder of modern testing, was not entirely atheoretic (Sternberg, 1990). All interesting theories of intelligence try to go beyond test scores to connect individual differences with a theory of how the mind works. Developing such a theory is the province of cognitive psychology.

Nevertheless, for the first seventy or so years of the twentieth century intelligence testing and cognitive psychology followed paths that, if not orthogonal, were not closer than 60 degrees to each other. At mid-century Cronbach (1957) called for a reorientation. Psychometricians and cognitive psychologists agreed, but, like supertankers turning, it took about twenty years to see either discipline change its course.

Switching metaphors gloriously, it now appears that troop movements in response to Cronbach's trumpet call did not occur until the 1970s. At that time my colleagues and I (Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975) conducted a series of studies in which we related the parameters of information processing theories, as measured by a variety of paradigms, to performance on conventional paper and pencil tests of verbal and mathematical reasoning. Foreshadowing much future research, we found that in university student populations there was a correlation in the −.3 range between the test scores and estimates of the performance parameters of models of reaction time for the paradigms that we used. The negative correlation is to be expected because the model parameters were all estimates of how long it took a person to perform a basic mental operation, such as looking up a word in a mental lexicon. Somewhat later Arthur Jensen (1982) conducted similar studies in which he related intelligence test scores to various parameters of choice reaction times. Once again the raw correlations were on the order of −.3.

Sternberg (1977) responded to Cronbach's call in a somewhat different way. Analogy problems were known to be good markers of general intelligence. Sternberg showed that the time required to solve analogies problems could be fractionated into different stages, such as encoding, mapping from one analogy to another, and verification of a hypothesized relation. In retrospect, it seems fair to say that Hunt et al. and Jensen were attempting to relate individual differences in information processing parameters to overall performance on the tests, while Sternberg was analyzing performance within test items.

At that point the dam broke. There is now a huge literature on individual differences in information processing. The topic is studied both for its own sake and because of the relation between information processing measures and scores on conventional intelligence tests, the psychometric definition of intelligence. The success of the effort is shown by the fact that some of the most active laboratories in the field are headed by people whose academic histories are completely independent of the original protagonists. Articles on individual differences in information processing appear regularly in all the major journals and constitute staple items for several of them.

The publication of this volume provides an opportunity to look back at what has been done and, with somewhat more hesitation, to attempt to identify what more needs to be done. Like any large intellectual movement, the study of information processing and intelligence has split into several subareas. The most important ones are reviewed in individual chapters in the current volume. I will try to take a larger view.

Cronbach wanted to establish a unity between two different ways of looking at human behavior. To understand what success we have had, we must know what these views are. They certainly are not the views that were held when Cronbach wrote.

Up to about 1957 behaviorism dominated human experimental psychology. This view did not lend itself to being connected to the factor-analytic view of differential psychologists. That connection had to wait for the replacement of behaviorism by information processing psychology. Modern cognitive psychology has now subsumed information processing, although information processing remains an important part of the expanded field. Similarly, differential psychology has moved well beyond the rigid view of counting factors that was implied by the data processing technology of half a century ago. To understand our present progress and future challenges, we need to see how cognitive and differential psychology look today.

THE CONCEPTS OF COGNITIVE PSYCHOLOGY

Theories and issues in cognitive psychology can be stated at the biological, information processing, or representational levels (Hunt, 2002). To understand the relation between cognitive psychology and theories of intelligence, we have to understand what these levels are.

At the biological level cognitive neuroscience attempts to associate information processing functions with brain mechanisms and processes. The idea is that the brain provides the mind with a toolkit of neural mechanisms to be used to build the functions of the mind: the ability to control attention, short- and long-term memory, maintenance of spatial orientation, and the like. The relevant mechanisms are to be located by direct observation or physiological intervention in the brain itself.

One level of abstraction higher, information processing psychology, a subset of cognitive psychology, attempts to characterize the mental functions themselves. To illustrate, memory is one of the most important aspects of human cognition; who we are is intimately tied to our imperfect remembrances of past experience. In 1957, when Cronbach wrote, memory was thought of as a unitary ability. By the 1970s the distinction between short-term and long-term memory was a basic tenet of cognitive psychology. Today we distinguish between at least half a dozen types of memories and make a strong distinction between storage and retrieval processes. The relation between the information processing and biological level is illustrated by modern attempts to identify the brain structures and processes that produce each of these different functional aspects of memory (Schacter, 1996). Because information processing measures can and have profitably been related to biological measures, information processing can be used to develop a link between biological measures and intelligence test scores.

Cognitive psychology is also concerned with higher levels of thinking, such as how people understand causation, solve logical and mathematical problems, and choose between alternative courses of action and even how religious upbringing influences one's understanding of evolutionary principles. This is cognition at the representational level because the issues to be studied are how people represent the world to themselves and how these representations influence their behavior. Representational-level thinking emerges from the brain, for the mind cannot have a thought that the brain cannot support. However, it turns out that this is a conceptual "bridge too far." It is more useful to think of representational-level thinking as emerging from the interaction between information processing capacities and the individual's social environment.

Outside of psychology the term "thinking" almost always refers to thought at the representational level. To a layperson psychological investigation of what eyewitnesses (or physics students) can be counted on to remember seems immanently reasonable. A psychological investigation of how people remember lists of arbitrary paired associates requires a bit more justification. The layperson has a point; ultimately we are interested in the thinking that reflects what people do, not how people behave in a laboratory setting.

What might cognitive psychology tell us about representational-level thinking? First, representational-level thinking emerges from the interaction between information processing capacities and an individual's social and physical environment. Accordingly, some common themes, dictated by information processing capacities, should apply to everyone. On the other hand, understanding the individual requires an understanding of both the format in which the information is held and the content of the information itself. The content is obviously a product of the individual's life history.

To remove the discussion from complete abstraction, I offer two examples. My treatment will be brief. For further discussion of these topics, see Hunt (2002, Chaps. 8–11).

The first, and clearest, is language. Modern linguistic theories assume that all human languages follow rather restricted information processing principles that govern, for instance, the permissible types of transformations from deep to surface structure. On the other hand, the natural languages are clearly different in many ways. The extent to which the form and content of a natural language influence the thought of its speakers (the *Whorfian hypothesis*) is a matter of debate. It would take us too far afield to explore the topic here. My point is solely that this is a reasonable topic for investigation, and one that could have considerable implications for individual variations in mental competence.

The second example involves the names of common animals. Cognitive psychologists interested in "thinking in general" have often investigated how American college students represent animal names as a way of understanding how classes are represented, and understanding how properties of classes and of individuals within a class influence both inductive and deductive reasoning. Lopez et al. (1997) developed models of knowledge about animals held by American college students and by the Itzaj Maya, a Central American group of forest dwellers. They found that the formal mechanisms for holding information about animals were similar for both groups. Animals were categorized by size, ferocity, certain biological properties, and ecological niche. However the weight placed on different dimensions of similarity varied. (The Maya placed more weight on ecological niche.) Furthermore, these differences led to understandable between-group differences in the conclusions that Americans and Maya reached when presented with evidence about new properties of animals, for example, that a certain animal was susceptible to an exotic disease. You could not understand the thinking of the groups unless you had an understanding both of culture-general "data structure" showing how information about animals was held and the culture-specific information about what each group knew, and what they regarded as important.

The sorts of issues I have just raised are ones that probably would not have even occurred to a behaviorist. By 1970 information processing psychology was a step beyond the behaviorist's insistence on unitary mechanisms of learning. As of the early twenty-first century the expansion had gone beyond information processing to look at brain processes in one direction and social–cultural correlates in another.

What had happened to theories of psychometric intelligence?

THEORIES OF PSYCHOMETRIC INTELLIGENCE

Psychometric intelligence has been buttressed by, and sometimes plagued by, the success or failure of technology. In the nineteenth century Galton attempted to account for individual differences in mental competence in terms of what we would now call information processing measures. He and his immediate successors failed, at least in their own eyes, because they could not find high correlations between their information processing tests and other indicators of intellectual competence, such as school grades. Interestingly, the correlations they did find are in the range observed in modern studies relating intelligence tests to information processing measures (Sternberg, 1990). The facts have not changed, but our definition of success has!

When Binet and Simon introduced the modern intelligence test, performance on such tests and in academics related to the test became the de facto definition of intelligence. For instance, Spearman's original argument for a general factor in intelligence was based on the analysis of the grades of English schoolchildren (Carroll, 1993). By 1957 when Cronbach sounded his trumpet, discussions of theories of intelligence had devolved into a debate over the factor structure of representative batteries of such tests: Do we have a single general factor (g) or are there multiple dimensions of individual differences *within the constraints of what had come, by convention, to be called "intelligence tests"*?

The one-factor versus multifactor debate has very largely been settled. Carroll (1993) showed that the best fit to the psychometric data is a three-layer model, very close to the one developed by Cattell (1971) and Horn (Horn, 1985; Horn & Noll, 1994). The Cattell–Horn model is based on the idea that there are three broad abilities: fluid intelligence (g_f), crystallized intelligence (g_c) and spatial-visual intelligence (g_v). Loosely speaking, g_f is the ability to develop solutions to relatively novel problems, g_c is the ability to apply previously learned solution methods to the current problem, and g_v is the ability to reason spatially. In most populations g_c and g_f are correlated, with the degree of correlation ranging anywhere from .5 to nearly 1.0. However, g_v tends to stand further apart, having correlations generally in the .4 to .5 range, or even lower, with g_c and g_f measures.

Because g_c and g_f are correlated, and often highly correlated, a number of authors (most notably Jensen, 1998; but see also Gottfredson, 1997) have argued that they are all manifestations of a single underlying construct, general intelligence (g). The argument is usually accompanied by a codicil in which it is stated that g_f and g are virtually identical, a point that is questioned immediately below.

The correlation between g_c and g_f could arise in two different ways. One, of course, is that something called general intelligence exists, and that tests of g_f and g_c are different manifestations of the same thing. The alternative is a sort of investment theory, first maintained by Cattell (1971), in which people invest their fluid intelligence in different learning experiences, and thus acquire g_c. A less-than-perfect correlation would be expected because different people, with identical g_f capabilities, might have different experiences and thus would acquire different levels of g_c.

Detterman and Daniel (1989), and since them several other authors in independent studies (Abad et al., 2003; Deary et al., 1996; Hunt, 1995b), discovered a fact that is important for this debate. Correlations between different intelligence tests are higher in populations of generally lower intellectual competence. With the exceptions of a few special syndromes (e.g., Turner's syndrome cases, where there is a selective loss of spatial-visual ability), correlations between test scores of mentally retarded individuals are quite high. By contrast, a great deal of differentiation of ability is seen in examinations of people whose ability is relatively high overall. Statistically, at low levels of ability a wide variety of tests load on a general factor, while at high levels of ability there is a pronounced g_c–g_f differentiation. Going still further, we would expect that people whose educational and life experiences differ (e.g., college students who pursue different majors, adults following different professions) would show distinctions within the

g_c field, depending upon precisely what aspects of previously acquired knowledge and problem-solving methods are being evaluated.

Today's definition of psychometric intelligence features (a) a strong general intelligence factor for the lower ranges of ability in the population, with a possible distinction between g and g_f and (b) differentiation along the g_f–g_c lines at higher levels of ability.

This theory is clearly well amplified beyond theories of intelligence circa 1957 and even circa 1975. The amplifications are very important for an attempt to unite the concepts of cognitive psychology to the concepts of intelligence theory. Three points stand out.

The first point is that the population matters. Information processing measures that depend upon fairly mechanistic performance, such as well-practiced reaction time measures or measures of perceptual speed, would be expected to have their greatest effect in populations where g is an important variable, because these measures presumably tap neural efficiency properties that apply to virtually all cognition. On the other hand, as specialized performance becomes more important, basic information processing capacity may be less important than the knowledge a person has and the strategies by which a person utilizes his or her capacity. Therefore correlations between simple information processing measures and intelligence test scores should increase when the sample is drawn from a population of lower general mental ability. Indeed, that is what Detterman and Daniel (1989) found.

The second point is that the test matters, especially when dealing with populations of average and above-average abilities. This caution is particularly important when intelligence theorists try to go outside of test scores to relate intelligence, as defined by a test, to the broader definition of intelligence defined by individual differences in competence in socially important areas. Much of the evidence for a connection between test scores and indices of success is drawn from studies using either the Wechsler Adult Intelligence Scale (WAIS), the Armed Services Vocational Aptitude Battery (ASVAB), or the Scholastic Assessment Test (SAT). The conclusion is usually that "general intelligence matters." See, for instance, discussions by Gottfredson (1997) and Herrnstein and Murray (1994). However, in the populations for which they were intended these tests load on crystallized intelligence (g_c), not g or g_f (Horn, 1985; Roberts et al., 2000). The importance of this distinction for the debate over whether intelligence counts "in the real world" is obvious. The importance of the distinction for the relation between cognitive psychology and the study of intelligence will be discussed later, when we look to the future of the relationship.

The third point has to do with the recurrent debate over whether intelligence is inherited. Present findings, based upon many studies of adoption and pedigree, show clearly that within the variety of environments that occur in the developed industrial societies, intelligence test scores behave as if they have heritability coefficients in the .5 to .8 range. Sadly, that convoluted sentence is necessary. Were studies to be conducted in societies with greater social heterogeneity (e.g., societies in which some groups are close to starvation or where some children's educations have been disrupted by war) or in societies with less genetic heterogeneity, we would expect the heritability coefficient to go down. What the present studies clearly do show is that under the conditions that apply to well over half the world, genetics does matter.

Tracing the information processing–test score link and tracing the genetic composition–test score link are both reductionist enterprises. Obviously no one inherits a test score in the same sense that a person inherits eye color. However, one might inherit information processing capabilities that would then, in appropriate environments, predispose a person to have a particular test score. Discouragingly, though, there has been relatively little exploration of this link.

Most attempts to respond to Cronbach's call have accepted the psychometric definition of intelligence. However, there are three major exceptions to this trend. Gardner (1983; Gardner, Kornhaber, & Wake, 1996) has argued for a much broader view. Gardner includes under intelligence such topics as individual differences in musical, social, and physical (motor control) skills. Sternberg and his colleagues in many writings (Sternberg, 1988, 1996; Sternberg et al., 2000) have been somewhat less catholic. They argue that conventional tests tap skills required in academic settings but fail to reflect individual differences in creativity (creative intelligence) and cognitive competence in everyday, nonacademic settings (practical intelligence). Goleman (1995) has argued for the existence of emotional intelligence, which he defines both as self-awareness of, and control over, one's own emotional reactions and an ability to recognize and react to other people's emotional state.

These movements have stricken a chord with a public that is somewhat wary of the idea that it is possible to evaluate a person's mental competence using a test that takes less than three hours to complete. A complete analysis of all the ramifications of these expansions of the "intelligence is what the tests measure" view is beyond the scope of this chapter. A few words are in order about how these expansions of the term "intelligence" might influence attempts to understand intelligence in terms of variations in individual information processing capacities.

Plato is supposed to have advised that in attempting to understand nature we should carve it at its joints. This is usually taken to mean that when we define a field of study, that field should be constrained along some recognizable lines. More formally, if x, y, and z are measurements of behaviors that are within a specific field (e.g., intelligence), then x should be sensitive to perturbations in y and z, and similarly for all other pairings. At the same time, x, y, and z should be relatively insensitive to, or should be responsive in the same way, to perturbations in a fourth variable, w, that is defined to be outside the field. Note that this implies that measurements of w, x, y, and z exist. Philosophy may be able to exist without measurement but science cannot.

As discussed later, we have a rather good idea of what information processing capacities are related to cognitive competence. We are also well on the way to identifying the brain structures that provide these capacities. Similarly, we are also well on the way to understanding the brain structures that underlie emotional responses (LeDoux, 2002). Most importantly, we know that the brain structures underlying cognition and emotion are not identical. This suggests that it might be a good idea to make a fairly strong distinction between individual differences in emotional sensitivity and individual differences in more "cold-blooded" cognitive skills. Of course, this conclusion mirrors the long-time practice in psychometrics, where a distinction is drawn between intelligence and personality tests.

Goleman's emotional intelligence and several of Gardner's multiple intelligences seem to fall more in the personality than the intelligence realm. This conclusion in no way diminishes the importance of studying these variables or of studying the interaction between traits identified in the personality and intelligence realms. It is a good idea to remember that personality and cognitive competence may well be two separate systems of individual variation.

Sternberg's expansion of intelligence, on the other hand, does retain a distinctly cognitive flavor. The measures that Sternberg and his colleagues have designed measure people's ability to identify culturally acceptable solutions to problems that (a) lie outside of problems that can be addressed using information that is typically taught in schools and (b) do not ask examinees to deal with virtually content-free problems in pattern induction. Sternberg et al. make two claims. They contend that performance on practical and creative problems should be considered in the definition of intelligence and they further contend that they have developed appropriate tests of creative and practical intelligence.

The first contention is a matter of definition, and I suspect that virtually no one would disagree. See, for instance, Gottfredson's (1997) discussion of the practicality of general intelligence, as measured by conventional tests.

The second contention is an empirical claim about tests that exist at a particular point in time. There are two ways that this contention could be rejected. One would be to show that *all* reliable variance in cognitive performance outside the testing arena is related to variance on conventional test scores. This is patently not true. The strongest advocates for the use of tests of general intelligence in personnel selection claim, at most, a correlation of .5 between test performance and job performance (Hunt, 1995a; Schmidt and Hunter, 1998).

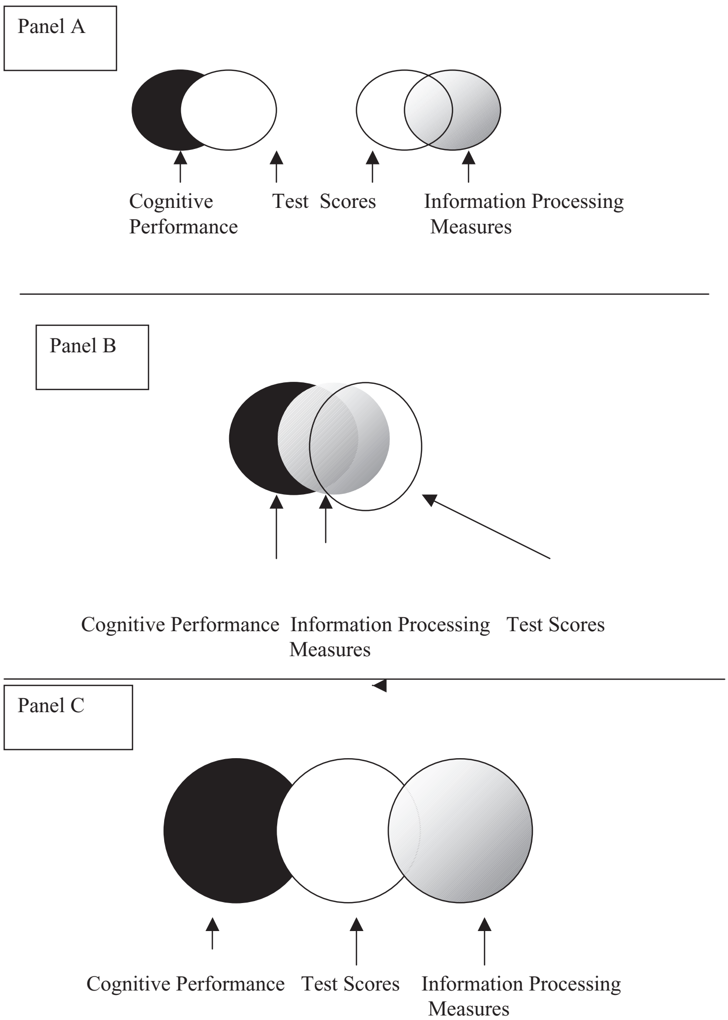

FIGURE 1. Possible configurations of shared variation between information processing measures, extra-laboratory performance, and conventional intelligence tests. The configuration in Panel A must exist, but it could be produced by the configurations in either Panels B or C.

Another way to reject the contention would be to show that all variation in cognitive performance not associated with test scores is associated with properties of the situation in which performance is assessed, rather than properties of the person being assessed. While this is not impossible in principle, at present no such demonstration exists.

Given that the contention cannot be rejected, can it be affirmed? This issue has to be settled on a case-by-case basis. See, for instance, the exchange between Brody (2003) and Sternberg (2003). The essence of that