# New and emerging models of human intelligence

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In the last decade, new models of human intelligence have altered the theoretical landscape in psychometrics and cognitive science. In the current article, we provide an overview of key distinguishing features of these new models. Compared to 20th century models of intelligence, the new models proposed in the 21st century are unique for three primary reasons; (1) new models interpret the general factor, or *g*, as an emergent property reflecting the pattern of positive correlations observed among test scores, not as a causal latent variable, and therefore challenge the notion of general ability, (2) new models bridge correlational and experimental psychology and account for inter-individual differences in behavior in terms of intra-individual psychological processes, and (3) new models make novel predictions about the neural correlates of intelligent behavior. © 2015 Wiley Periodicals, Inc.

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## INTRODUCTION

Intelligence is one of the most extensively investigated constructs in the history of cognitive science. Despite this research effort, or perhaps because of it, there is still no single consensus definition, model, or theory of human intelligence. The purpose of the current article is to provide an overview of *new models* of intelligence. The field of intelligence is currently in a stage of significant progress, so our goal here is to convey to a broad audience what is novel and exciting about these so-called new models.

Given the focus on what is new, the current article does not address old controversies or political arguments about intelligence research. In our opinion, the field has finally moved beyond all that. A new generation of intelligence researchers, equipped with more advanced statistical methods and a more sophisticated understanding of the brain, are asking much more compelling questions about cognitive abilities. As we embark upon the second century of intelligence research, there is opportunity, and reason, for a fresh perspective and new approach to the science of intelligence.

The article also does not provide a formal definition of intelligence. As mentioned, there is no consensus definition of the term. Thus, in order to be objective here, we could only provide a list of acceptable definitions, rather than *the definition*. More importantly, most previous definitions (apart from the one, 'Intelligence is what IQ tests measure',[1]) revolve around the interpretation of the general factor of intelligence as something that is *reflected* by IQ tests. That is, these definitions implicitly adhere to the idea that there is something out there that we can call intelligence, and this single construct is measured by a variety of different ability tests. In this article, we argue that this interpretation is incorrect: intelligence, best defined, is a set of different cognitive abilities rather than an overarching, general mechanism involved in all cognitive activity.

Of course, the debate on general ability versus multiple abilities has been around for over a century now, so what is new, or different, about 'new models' of intelligence? In our view, a lot, but let us start with a glimpse of just three recent developments in the field of intelligence research. We will elaborate upon each of these topics later.

- The general factor of intelligence, or *g*, which is reliably observed when the all-positive covariance matrix of mental test scores is

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factor analyzed, is interpreted as an emergent rather than a latent property. That is, instead of interpreting *g* as a causal general ability, implicitly linked to a unitary psychological trait, new models interpret *g* as an emergent property and individual scores on *g* as an index of the collective performance on a battery of tests. In less technical terms, according to new models of intelligence, *g* does not have a causal influence on test scores, which means that the concept of 'general ability' is not a necessary feature of a theory of intelligence. To be clear, new models of intelligence do not deny the existence of *g*, it clearly exists, and is predictive of many important life outcomes.[2]

- New models of intelligence can formally connect psychometrics and cognitive science in a computational manner. In psychometrics, the purpose of a 'model' is to explain the pattern of correlations among test scores, i.e., the covariance structure, in terms of a latent variable model and to explain responses to test items in terms of item response models. In cognitive science, the goal of a 'model' is to provide a computational account of the cognitive processes involved in the performance of some cognitive task. It has been argued that computational models have greater scientific potential in cognitive science than theoretical frameworks because they make more specific, quantifiable predictions about the processes being modeled. New models of intelligence are attempting to connect these different modeling approaches. The goal is to fit psychometric models with parameters from cognitive models and thereby account for inter-individual differences in behavior in terms of intra-individual psychological processes, and do so in formal mathematical fashion, such that proposed models can be subject to novel predictions, objectively falsified, and updated.
- New models of intelligence make novel predictions about the neural bases of intelligence and these predictions are being met with a staggering amount of new data from neuroscience. Theories of intelligence have always been informed by our scientific understanding of the brain but now, with the rise of neuroimaging methods, neural data from large samples of healthy subjects are being combined with behavioral data, allowing for much more accurate predictions about the neural bases of intelligent behavior.

It is important here at the outset to clarify the distinction between a *theory* of intelligence and a *model* of intelligence. A theory is a set of ideas intended to explain something or some type of phenomenon and is based on general principles independent of the thing, or the phenomenon, being explained. Strong theories make empirical predictions and are therefore falsifiable. In contrast, a model is an implementation of the theory. In order to implement a theory, a particular modeling framework must be adopted, and certain assumptions may be necessary for the model to operate in a manner consistent with the theory.

It is also important here at the outset to clarify the distinction between two broad categories of models in cognitive science: psychometric and cognitive. Psychometric models have dominated the landscape of intelligence research and will be described in more detail below. In short, psychometric models attempt to capture the structure of intelligence but often times fail to convey much information about function. In contrast, cognitive models of intellectual behavior, such as reasoning and working memory, attempt to capture the cognitive processes involved in complex cognition but often fail to explain individual differences in performance.

To appreciate the divide between psychometric models of intelligence and computational models of cognition, let us take a look at two contemporary and highly influential models: the Cattell-Horn-Carroll (CHC) model of intelligence[3–5] and the embedded-process model of working memory.[6–8] The CHC model is presented in Figure 1 and the working memory process model is presented in Figure 2.

The CHC model provides an excellent fit to a broad range of individual differences data and is therefore considered one of the best, if not the best, latent variable models of intelligence in the psychometric literature. According to the hierarchical model, there is a general factor at the apex, which has a causal influence on several 'broad stratum' factors, and these factors in turn have a causal influence on 'narrow stratum' factors, and these factors in turn have a causal influence on test scores. As mentioned, the CHC provides a comprehensive account of covariance structures, but it does not translate well into a cognitive process model. For instance, Carrol[4] does not specify what *g* represents in terms of a cognitive process, nor does he explain the causal mechanism relating *g* to other factors. To be fair, that is not the primary goal of a latent variable model.

In contrast, consider the working memory model in Figure 2. It provides a detailed account of the cognitive processes involved in perception, attention, and memory, and each component of the model is supported by decades of cognitive experimental psychological research. For example, the focus of

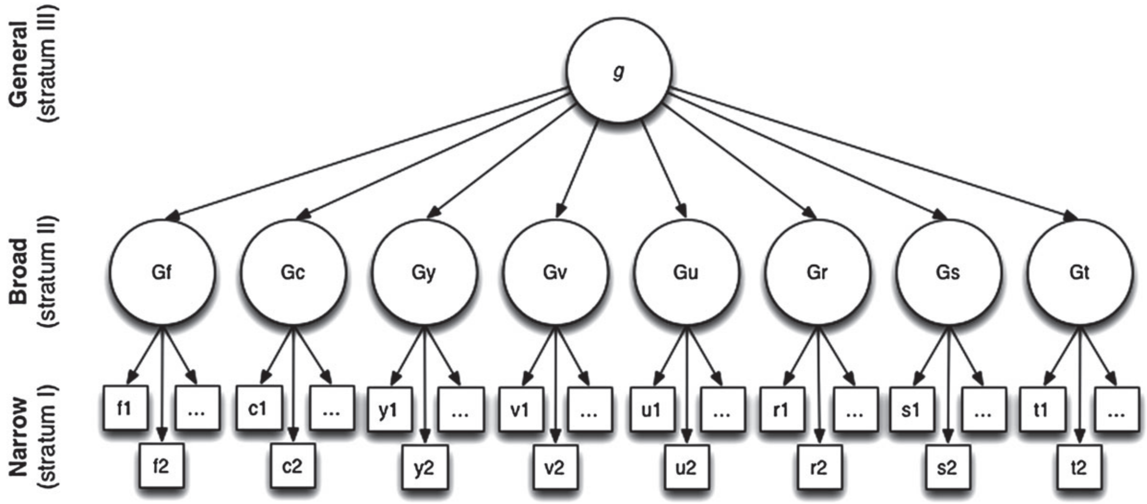

**FIGURE 1 |** The Cattell-Horn-Carrol (CHC) latent variable model of intelligence.

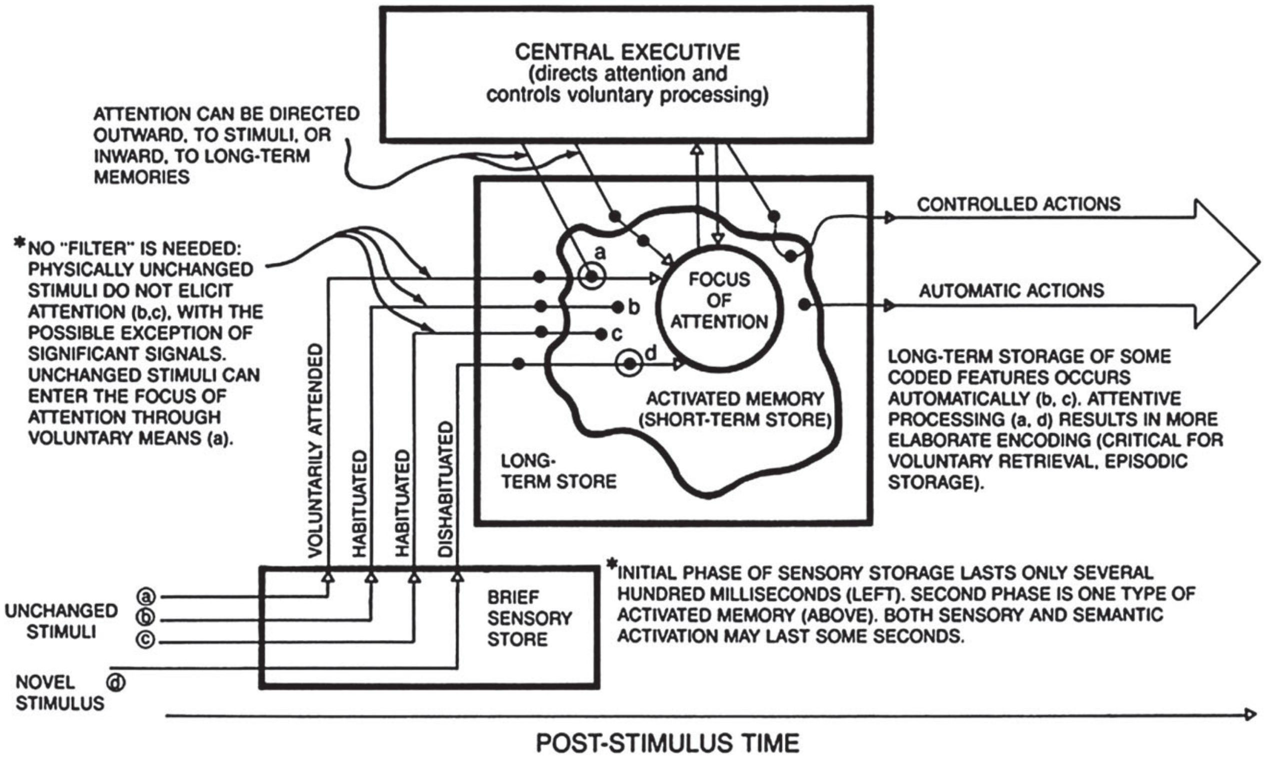

**FIGURE 2 |** The embedded-process model of working memory.[6]

attention is limited to a small number of memory representations, and information maintained in this state is more readily accessible than information represented in the short-term store, and this information is more readily accessible than information represented in the long-term memory.[6] As another example, note that novel stimuli, unlike habituated stimuli, can capture attention and gain immediate access into the focus of attention. To be clear, there are many other models of working memory, with similar features, but it is fair to say that the embedded-process model is among the most influential models of working memory in cognitive science. Yet, looking at the model, one is left guessing as to which of the components gives rise to variation in task performance across individuals. Again, to be fair, that is not the primary goal of this type of model.

The point of this 'model comparison' exercise is to demonstrate that these two models have different primary goals. The primary goal of latent variable models is to explain covariance structures and the primary goal of cognitive models is to explain the processes involved in complex cognitive behavior, from a nomothetic perspective. As a result, one adheres to the correlational discipline of psychology and the other adheres to the experimental discipline. To be fair, some researchers have attempted to bridge these two disciplines, especially in the realm of working memory and its relation to fluid intelligence (for example, Ref 8, 9); indeed, this work lays the foundation for one of the theoretical frameworks, Process Overlap Theory, which we will discuss in more detail below.

In sum, new models of intelligence are attempting to provide a more unified perspective. The goal is to both (a) account for individual differences in behavior, on par with the CHC model, and (b) provide a cognitive process account of behavior in terms of intra-individual psychological processes, on par with the working memory model.

## HISTORICAL PERSPECTIVE

The first, and perhaps the most well known, theory of intelligence is general intelligence theory.[10] Spearman initially argued that the positive pattern of correlations so often observed among test scores, which we refer to here as the positive manifold, was due to a single general ability factor (some kind of energy or power) that has a causal influence on the performance of all tests. This was represented by a latent variable model, consisting of a general factor, now famously known as Spearman's *g*, and the causal paths from the general factor to all tests.

Following Spearman, several alternative theories and models of intelligence were proposed in the first half of the 20th century. Factor analysis and latent variable models were used to test competing theories. For example, after Spearman's initial work, it became immediately clear that a single factor model could not account for the patterns of convergence and divergence within the positive manifold and so alternative models proposing various 'group factors' emerged. Group factors typically represent more domain-specific constructs, such as verbal ability and visual–spatial skills. Perhaps the most influential of these models was Thurstone's Primary Mental Abilities model, according to which there are several group factors but – initially – no general factor.[11] This type of latent variable model has also been rejected because group factors are typically correlated and so models that incorporate both a general factor and lower order group factors provide the best fit to data. This helps to explain why this historical line of research culminated in the CHC model. Looking back, it is interesting to notice that despite substantive differences among early theorists, they each attributed an important role of reasoning, learning, problem solving, and comprehension in human intelligence.

In the 1970s and 1980s, this conception of intelligence was criticized as too narrow, and as a result, theories and models emerged that differed substantially from prior work. For example, the triarchic theory of intelligence challenged the status quo definition of intelligence and proposed that there are other psychological processes and behaviors that can be beneficial in school, work, and society in general, and should therefore be considered expressions of intelligence. The triarchic theory included analytic intelligence but added creativity and practical intelligence.[12] Moreover, this approach conveyed that there are different cognitive processes underlying these different forms, or components, of intelligence.

In the 1980s, an even broader view of intelligence was proposed, called multiple intelligence theory. According to the multiple intelligence theory, there are at least eight independent abilities that should be conceived as forms of intelligence, including musical ability, kinesthetic ability, and interpersonal ability, among others.[13]

Sternberg and Gardner challenged the status quo approach to intelligence, especially in psychometrics, and their ideas garnered a great deal of popular attention. However, despite some initial success linking information-processing models to theories of intelligence (for a review, see Ref 12), these theoretical frameworks ultimately failed to generate sustainable programs of research, especially when compared to the theoretical frameworks that preceded them.

Indeed, by the end of the 20th century, the most widely accepted theoretical framework in the field of intelligence was the CHC model, which is much more consistent with original theories of intelligence proposed by Spearman and Thurstone than it is with the theories of Sternberg or Gardner. Again, according to the CHC theory, the structure of intelligence is hierarchical, with general intelligence, or *g*, at the apex, and multiple group factors, akin to Thurstone's Primary Abilities, at the level below *g*. Among these group factors are fluid intelligence and crystallized intelligence, a distinction first proposed by Cattell[3] and Horn.[5] While crystallized intelligence refers to the skills and knowledge one acquires in the enculturation process, broadly speaking, fluid intelligence is defined as 'an expression of the level of complexity of relationships which an individual can perceive and act upon when he does not have recourse to answers to such complex issues already stored in memory' (Ref 14 p 99) The fluid/crystallized distinction has been influential because it explains individual differences data and it has been supported, broadly speaking, by experimental research. For example, cognitive aging research demonstrates that fluid intelligence declines with age but crystallized intelligence does not.[15] Also, neuroimaging research suggests distinct neural correlates underlying performance of tests of fluid intelligence versus crystallized intelligence.[16] Finally, tests of fluid intelligence are strongly correlated with measures of working memory capacity, whereas the correlations between tests of crystallized intelligence and working memory capacity are weak.[17] These, and other findings, helped to blur the line between correlational and experimental psychology.

## NEW MODELS OF INTELLIGENCE

The last decade has seen the birth of novel theoretical approaches to human intelligence. In this section, we survey a few important consequences of three of these: the (reformulated) sampling model, the mutualism model, and the process overlap theory. Albeit offering different accounts of the positive manifold, a common aspect of these theories is that they all point out that general intelligence, a single common cause of the positive correlations between mental tests, is surely a sufficient, but definitely not a necessary, explanation. That is, even though they acknowledge the existence of *psychometric g*, they doubt the existence of *psychological g:* a cognitive process or mechanism that could be equated with the general factor. Yet, as we shall see, this approach has substantial consequences on the conceptualization of psychometric *g*, too.

The first 'new' model, the 'sampling model' or 'bonds theory', is not entirely novel; in fact, it was first established in 1916 by Godfrey Thomson, a contemporary of Spearman. Thomson demonstrated that the positive manifold can emerge without a general factor if there is an almost infinite number of psychological components, some of which are tapped by a large number of tests: 'The mind, in carrying out any activity such as a mental test, has two levels at which it can operate. The elements of activity at the lower level are entirely specific, but those at the higher level are such that they may come into play in different activities. Any activity is a sample of these elements'.[18]

In the 100 years since its formulation, there have been statistical elaborations and extensions of the sampling model (e.g., Ref 19), but its modern version and the statistical reformulation it is based on is mostly due to Bartholomew et al.[20,21] The most important part of their work is a mathematical demonstration showing that there is no statistical means of distinguishing between *g*-models and the sampling model: even though they are conceptually very different, they can equally account for the positive manifold and hierarchical structure in intelligence. That is, Bartholomew et al.[20] provide a mathematical proof illustrating that *both* general factor models and sampling models can provide an adequate fit of the covariance structures typically observed when a large battery of tests is administered to a large sample of subjects.

This is a pivotal turning point for the field because it implies that comparing the fit of different types of latent variable models no longer provides any theoretical leverage whatsoever when evaluating competing theories of intelligence. The larger implication here is that the field must move beyond psychometrics and take a converging operations approach, considering evidence from other fields, such as cognitive science, developmental psychology, and neuroscience.

The second theoretical account of the positive manifold to discuss is the mutualism model, a developmental account of the positive manifold, inspired by mathematical models in ecology. Mutualism assumes that positive reciprocal interactions take place between cognitive processes during development. According to this model, at the beginning of development, individual differences in cognitive abilities are uncorrelated. The positive manifold, and thus the structure of individual differences in intelligence, is the result of mutually beneficial interactions between modules or processes. In adults, tests unidimensionally tap specific cognitive capabilities, but they are still correlated because of their interaction during development. Just like sampling, this model is also capable of providing a mathematical explanation of the positive manifold without assuming the causal action of a single general factor.[22]

The third novel explanation of the positive manifold is process overlap theory, a novel sampling account, based upon cognitive process models, specifically models of working memory.[23] In particular, the theory draws substantially on the finding that the positive manifold is not confined to covariance matrices of the intelligence literature: it is also commonly observed in working memory tasks. The theory assumes that any item or task requires a number of domain-specific as well as domain-general cognitive processes and their corresponding neural mechanisms. Domain-general processes involved in executive attention, and mainly tapping the dorsolateral prefrontal cortex, are central to working memory task performance. That is, they are activated by a large number

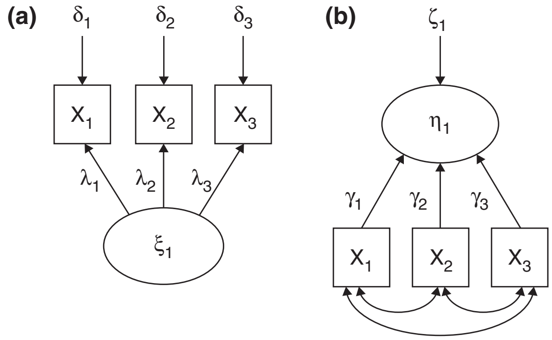

**FIGURE 3 |** Illustration of a reflective latent variable (a) and a formative latent variable (b).

of test items, alongside with domain-specific processes tapped by specific types of tests only. Such an overlap of executive processes explains the positive manifold as well as the hierarchical structure of cognitive abilities.

Even though these theoretical accounts are very different, a common characteristic is that they all challenge the idea that the across-domain correlations between diverse mental tests are caused by an underlying factor; instead, they propose that the positive manifold is an emergent property. This idea has a number of important consequences for the modeling of human intelligence. In order to understand these implications, one has to briefly familiarize with the concept of reflective and formative models, illustrated in Figure 3.

The model on the left is a *reflective* model, which is the standard approach in psychology. This model requires a stance of *entity realism* with respect to the modeled construct.[24] Simply, in order for reflective measurement to make sense, one must assume that there is something out there, represented by the construct, and the measures are (imperfect) indicators of this something. In the case of *g*, it is assumed that *g* causes the measures as well as the covariance among the measures. According to the theory of general intelligence, *g* causes the measures because, ceteris paribus, a person's score on the measure, i.e., the IQ test, is determined by his/her score on the latent variable i.e., *g*. Consequently, someone having a higher position on the *g* factor will have a higher score on the IQ test than someone with a lower position on *g*, and therefore variance in the latent variable determines variance in the measure. Finally, the measures' covariance is caused by the latent variable, because any two IQ tests covary to the extent to which they covary with *g*.

In formative models, the chain of causation is the opposite. The latent variable emerges *because* of the indicators and not the other way around,[a] hence *g* is the result, rather than the cause of the correlations between group factors. Similar formative latent variables are socioeconomic status (SES) and general health, each of which tap the common variance between measures, but do not explain it – according to sampling, mutualism, and process overlap theory, *g* is no different. Moreover, *g* can even be treated as a weighted sum-score: if the unique variance of the formative latent variable, noted with $\zeta$ in Figure 3, is removed, then *g*, interpreted as general intelligence, is indeed simply determined by what IQ tests measure.[25]

The difference in the direction of causality between formative and reflective models has drastic implications.[26,27] In reflective models, the latent variable is a *common cause* of the indicators, whereas in formative models, it is their *common consequence*. Because in reflective models, measures are indicators of the latent construct, they are interchangeable. For instance, tests of vocabulary and general knowledge both purportedly measure crystallized intelligence; if one of the measures is replaced by the other in a model, the theoretical meaning of the construct is supposed to be unaltered. A formative latent variable, on the other hand, is determined by its indicators, which cannot be interchanged without a corresponding change in the conceptual interpretation of the construct.

Besides purely formative and reflective models, there are hybrid models, which are in part reflective, in part formative (e.g., Ref 28). These models have latent variables that are causing, as well as the ones that are, the result of covariance. Process Overlap Theory provides exactly such a hybrid model.[23] In the model, group factors on the lower levels of the hierarchy reflect real cognitive abilities; hence, they are indeed reflected by individual measures, and they have a causal effect on the measures' covariance. On the highest level of the hierarchy, *g* emerges as a formative construct, which is caused by the covariance between the group factors. That is, the general factor does not explain the correlations between group factors – according to Process Overlap Theory, it is explained by the overlap between processes tapped by tests that measure the individual group factors.

The issue of formative measures will not be further dealt with here. The take-home message is that new models of intelligence that explain the positive manifold without postulating a *causal* general factor have overwhelming consequences on how a general factor can be interpreted to be in accordance with these models. The analysis of such consequences is only beginning to unfold, and future research on the modeling of intelligence will probably involve a thorough elaboration on how a formative general factor can be conceptualized. It is predictable, however, that a general factor so interpreted will be more a tool for predicting real-life outcomes than a concept appropriate for theory testing – the latter will probably be restricted to group factors, which do fit to a realist ontology.

## FUTURE DIRECTIONS

Given these new models, where is intelligence research headed? Our prediction is that future research will be highly interdisciplinary. For example, more work is needed to link psychometric models of intelligence and computational models of working memory. On the topic of the neural correlates of intelligence, psychometric issues with respect to neural measurement are just beginning to be explored in the realm of neuroimaging. Research teams will require a working knowledge of measurement theory, neuroscience, and imaging methods. Finally, more work is needed in developmental psychology and this work too must be able to bridge psychometrics, cognitive science, and neuroscience. Fortunately, large datasets are being acquired in all of these fields; for example, large sample neuroimaging studies are much more common now than just 5 years ago. Also, there seems to be a greater appreciation now for implementing longitudinal designs to explore change within individuals over time, especially in early childhood and in later stages of life. This is all good news for the future of the field.

So it seems that the field of intelligence is moving full steam ahead, equipped with new theoretical frameworks and more advanced and statistically powerful research methods. However, there is one thing that we, as intelligence researches, must improve – the teaching of intelligence. The current lack of formal course instruction on the topic of intelligence, especially at American Universities, is alarming. The majority of students who earn a college degree in psychology today are likely to know very little about the science of intelligence testing. This is a serious problem, especially given the societal impact of standardized tests and assessment of academic achievement. For decades now, these topics have generated serious contentious debates, and sadly the science of testing is rarely part of the conversation, in large part because the science is not well understood. As these exciting new research programs develop, we must also promote the teaching of the science of intelligence, to inform future generations of parents, educators, and policy makers and to inspire the next generation of intelligence researchers.

## NOTE

[a] This fact has motivated a few authors to not even call formative constructs latent variables. We will keep the term, however, emphasizing the fact that both formative and reflective constructs are unobservable.

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## REFERENCES

1. Boring EG. Intelligence as the tests test it. *New Repub* 1923, 36:35–37.
2. Gottfredson LS. Where and why *g* matters: not a mystery. *Hum Perform* 2002, 15:25–46.
3. Cattell RB. Some theoretical issues in adult intelligence testing. *Psychol Bull* 1941, 38:592.
4. Carrol JB, *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*. Cambridge: Cambridge University Press; 1993.
5. Horn JL. Fluid and crystallized intelligence: a factor analytic and developmental study of the structure among primary mental abilities. Unpublished doctoral dissertation, University of Illinois, Champaign, 1965.
6. Cowan N. *Attention and Memory: An Integrated Framework*. Oxford Psychology Series, vol. 26. New York: Oxford University Press; 1995.
7. Cowan N. *Working Memory Capacity*. Hove, East Sussex: Psychology Press; 2005.
8. Cowan N, Elliott EM, Saults JS, Morey CC, Mattox S, Hismjatullina A, Conway ARA. On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cogn Psychol* 2005, 51:42–100.
9. Engle RW, Kane MJ. Executive attention, working memory capacity, and a two-factor theory of cognitive control. In: Ross B, ed. *The Psychology of Learning and Motivation*, vol. 44. New York: Elsevier; 2004, 145–199.

10. Spearman C, General intelligence, objectively determined and measured. *Am J Psychol* 1904, 15:201–292. doi: 10.2307/1412107.
11. Thurstone LL. *Primary Mental Abilities*. Chicago, IL: University of Chicago Press; 1938.
12. Sternberg RJ, Beyond IQ. *A Triarchic Theory of Intelligence*. Cambridge: Cambridge University Press; 1985.
13. Gardner H. *Frames of Mind*. New York: Basic Book Inc; 1983.
14. Cattell RB. *Abilities: Their Structure, Growth, and Action*. Boston: Houghton Mifflin; 1971.
15. Horn JL & Cattell RB. Age differences in fluid and crystallized intelligence. *Acta Psychol* 1967, 26:107–129.
16. Kane MJ. Full frontal fluidity? Looking in on the neuroimaging of reasoning and intelligence. In: Wilhelm O, Engle RW, eds. *Handbook of Understanding and Measuring Intelligence*. Thousand Oaks, CA: Sage; 2005, 141–163.
17. Conway ARA, Kovacs K. Individual differences in intelligence and working memory: a review of latent variable models. *Psychol Learn Motiv* 2013, 58:233–270.
18. Thomson GH. A hierarchy without a general factor. *Br J Psychol, 1904–1920* 1916, 8:271–281. doi:10.1111/j.2044-8295.1916.tb00133.x.
19. Maxwell AE. Factor analysis: Thomson's sampling theory recalled. *Br J Math Stat Psychol* 1972, 25:1–21. doi:10.1111/j.2044-8317.1972.tb00474.x.
20. Bartholomew DJ, Allerhand M, Deary IJ. Measuring mental capacity: Thomson's Bonds model and Spearman's g-model compared. *Intelligence* 2013, 41:222–233. doi:10.1016/j.intell.2013.03.007.
21. Bartholomew DJ, Deary IJ, Lawn M. A new lease of life for Thomson's bonds model of intelligence. *Psychol Rev* 2009, 116:567–579. doi:10.1037/a0016262.
22. Van der Maas HLJ, Dolan CV, Grasman RPPP, Wicherts JM, Huizenga HM, Raijmakers MEJ. A dynamical model of general intelligence: the positive manifold of intelligence by mutualism. *Psychol Rev* 2006, 113:842–861. doi:10.1037/0033-295X.113.4.842.
23. Kovacs K, Conway ARA. Process overlap theory: a unified account of human intelligence. *Behav Brain Sci*. Forthcoming.
24. Borsboom D, Mellenbergh GJ, Van Heerden J. The theoretical status of latent variables. *Psychol Rev* 2003, 110:203–219.
25. Van der Maas H, Kan K-J, Borsboom D. Intelligence is what the intelligence test measures. Seriously. *J Intell* 2014, 2:12–15. doi:10.3390/jintelligence2010012.
26. Bagozzi RP. On the meaning of formative measurement and how it differs from reflective measurement: comment on Howell, Breivik, and Wilcox (2007). *Psychol Methods* 2007, 12:229–237; discussion 238–245. doi:10.1037/1082-989X.12.2.229.
27. Howell RD, Breivik E, Wilcox JB. Reconsidering formative measurement. *Psychol Methods* 2007, 12:205–218. doi:10.1037/1082-989X.12.2.205.
28. Edwards JR. The fallacy of formative measurement. *Organ Res Methods* 2011, 14:370–388. doi:10.1177/1094428110378369.

## FURTHER READING

McFarland DJ. A single g factor is not necessary to simulate positive correlations between cognitive tests. *J Clin Exp Neuropsychol* 2012, 34:378–384. doi:10.1080/13803395.2011.645018.