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Editorial

Intelligence, Where to Look, Where to Go?

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1. Introduction

The first issue of the Journal of Intelligence is devoted to a discussion based on the following two questions:

1. What are the most important scientific issues in the domain of human intelligence?
2. What are the most promising new ideas and approaches in the study of human intelligence?

To begin this discussion, members of the editorial board of our journal have sent their answers to the above questions. Next, the same two questions, and the various answers to them, have served as input for two invited articles published in this issue, one by Wendy Johnson, and another by Earl Hunt and Susanne Jaeggi. I thank the members of the board who have participated, and we are very grateful to the authors of the two invited articles for sharing their ideas with us. We are glad these stimulating and inspiring reflections can be offered to our readers as the first step of a larger plan with this first issue. Our next step is to proceed with comments, again by members of the editorial board and by other scholars.

Let me give a summary of the answers from members of the board. The full texts can be found in the Appendix to this editorial. The summary is organized in three categories depending on how much agreement or divergence there is. The categories are agreement, no divergence, and divergence. Attention will mostly be given to the divergence category, and the issues from that category will be briefly discussed.

2. Agreement

2.1. Neural Substrate and Processes

The participants of the preliminary discussion largely agree that the neural substrate and processes are important and promising to investigate, with brain imaging and other approaches. Understanding what in the brain accounts for intelligence is considered a major aim of intelligence research. This includes the location of brain activity, as well the density of neurons, the size and connections of areas, the functioning of the brain as a system, and changes in the brain as a consequence of learning and experience, commonly called brain plasticity.

2.2. Better Measurement

Several participants insist that the measurement of intelligence can and should be improved. The suggestions for improvement are of a psychometric and substantive kind. Some psychometric suggestions refer to classic measurement aspects such as construct validity, and other refer to the quality of psychometric modeling. The more substantive suggestions point to a type of data other than from classic intelligence tests, such as data regarding real world activities in real time, and data from games and virtual reality tasks.

3. No Divergence

Many interesting points came from one or a few participants and do not show divergence. This does not make these suggestions less valuable. An interest is expressed in the effects of pharmaceutical ingredients, cognitive enhancers, the environment and lifestyle, in the CHC model, longitudinal studies, big data, implicit learning, social impact, item generation, and in artificial intelligence. These are all important topics, some of which imply that more attention is given to other disciplines. For example, engineers are building intelligent systems and systems of artificial intelligence. The domain within psychology where there is some interaction with engineering is mainly cognitive psychology, but surprisingly the domain of human intelligence has not interacted much with engineering.

4. Divergence

Perhaps the most interesting topics from a discussion point of view are those where there is a divergence in opinion and way of thinking. We will discuss four such topics, but two stand out. The first of these two is the importance of a definition, and the second is how broad a definition should be.

4.1. Definition?

Most participants believe that a definition is important. A good definition is seen as a condition for progress. A definition must be sufficiently clear and widely accepted in the discipline. However, the issue is raised whether the definition of intelligence should come first, or whether instead the findings from the loosely delineated domain of intelligence should lead us to define more sharply what intelligence is. In other words, must a definition be based on research or should research be based on a definition?

Surprising or not, earlier efforts for a definition have not worked well [1,2] and, in fact, scholars tend to stay away from definitions. Does it mean the definition is self-evident? Is a definition too difficult? Are the differences in opinion too large to bridge? Is there an implicit or even explicit belief that a definition does not pay off? Or are there still other reasons? Would a definition be experienced as a restriction? Will it ever be possible to reach an agreement, and, if so, what would it depend on? These are all questions that are worth further discussion.

4.2. How Broad?

How broad should the definition of intelligence be, and similarly how broad should the intelligence domain be and what is the range of tasks, activities, and competencies to be studied? Interestingly, broad does not only mean the inclusion of social, emotional, and personality related competences, but also cognitive aspects that are not commonly associated with intelligence tests, such as learning strategies, expert performance, implicit learning, and the cognitive unconscious. These are refreshing ideas. In the correlational sense, broad means broader than variables correlated with g. This means going beyond the positive manifold.

The answer to the question of whether the concept of intelligence should be broader than what is assessed in the common intelligence tests would probably be a unanimous yes. The opinions start to diverge when the question is how broad and what to include. Thinking in terms of a geographic analogy, broader implies an extension of the territories. Let us assume that the positive manifold is a continent. Are there still unknown territories on the continent? Should we reach out to islands and to other continents and annex these to Intelligence land? Can intelligence be thought of as an archipelago of neighboring islands and how can the archipelago be delineated?

If the domain of intelligence is extended beyond variables that correlate with g and thus beyond the positive manifold, then the unifying principle cannot be found in the correlations and thus not in correlated individual differences. Can the uniting principle be of a different kind? Or is a uniting principle not needed? Can intelligence be an archipelago of dispersed islands? If the included variables do not share a positive inter-correlation, what do they share instead in order to be included in the concept of intelligence? Attempting to answer such questions brings us back to the definitional issue.

4.3. Kind of Variation?

Other topics are not really a source of disagreement but rather a source of somewhat divergent focuses. The kind of variation to investigate is one such example. Opinions do not differ so much on which types of variation are interesting to study, but on which to focus on primarily. Variation can be studied across individuals, across age, across history, from pre-intervention to post-intervention, simply within individuals without any intervention, and also through development. The dominant focus still is on inter-individual variation as established in test scores. Individual differences in cognitive psychological experiments are rapidly gaining more interest. It is in fact also possible to study development and change in the size and kind of individual differences, but that is almost never done. Some of the participants argue that also other types than inter-individual variation must be studied, such as malleability, brain plasticity, cognitive enhancement, *etc*., with a focus on intra-individual variation as a consequence of interventions, learning, and experience.

4.4. Genetic Basis?

The field seems to have given up on the specification of the genetic basis of intelligence and its delineation from the environmental contribution. The correlations and the intrinsic interactions between genetic and environmental aspects seem too complicated for a research program to make sense at this point in time. It is perhaps an unspoken issue whether one should try harder to unravel the correlations and interactions, for example in a dynamic system and a systems theory approach, or whether one better focuses on more promising short-term endeavors.

Perhaps the most important given of the present time is that the field seems to be in a transition stage, between the more classic test approaches and the more recent biological and brain study approaches. Research will most likely move further in the neuroscience direction. It is also the case that neuroscience journals publish articles with relevance to intelligence. However, in many cases, intelligence test scores are used as a criterion variable. That does not seem to change. The concept of intelligence seems inseparably linked to intelligence tests. Brain research often consists in looking for correlates in the brain.

Conflicts of Interest

The author declares no conflict of interest.

Appendix

a) Editorial Board Discussion: First Round Contributions

Andrew R. A. Conway (Princeton University; E-Mail: aconway@princeton.edu)

1. What are in your view the most important scientific issues in the domain of human intelligence?

(a) Theory: New theories of intelligence must cross traditional disciplinary boundaries. It is clear that new theories that are able to unite previously disparate groups will thrive while new theories that create yet more division will not. Also, this should go without saying but a new theory must pose new predictions and therefore be falsifiable. Finally, as a community we must embrace the fact that there are multiple levels of analysis (e.g., Marr, 1982 [3]) and all will be important for a complete understanding of human intelligence. (b) Constructs: Construct development, to me, is the most ubiquitous and obvious flaw in current intelligence research. There is a need for more explicit definitions for all constructs currently under investigation. Also, to build a serious and sustainable program of research in intelligence one must vigilantly evaluate all aspects of construct validity. In particular, it is essential to establish both convergent and divergent validity. That sounds easy but in practice it's actually quite hard because it requires more resources (more tasks, more running time) and often more statistical power (subtle differences between constructs require more power to detect). (c) Measurement: Reliability is of course essential, particularly when data collection is expensive, which is the case for neuroimaging. That said, the field should continue to invest in new methods, even if the initial costs are steep. (d) Teaching: Intelligence became such a controversial topic in the 20th century that now very few colleges in the United States offer even a single course on it! We need to change

that by educating our colleagues and administrators that there's nothing to fear. Key word: objectivity! None of us are perfect but we should always strive to be objective and not let our personal beliefs, political convictions, or other issues influence our science. (e) Impact: It is an understatement to say that a fundamental change in intelligence theory will have broad societal impact. For example, current conventional wisdom holds that psychometric g reflects a general cognitive ability and one's relative position on g remains relatively stable over time. Recent work calls into question both of these arguments. If indeed there is no such thing as general cognitive ability and/or if indeed one's relative position can be changed through training, intervention, or medication then traditional theories of intelligence will have to be radically revised and eventually these new views will seep into popular culture. An exciting possibility is that intelligence will eventually be viewed as just one aspect of human health and performance. Intelligent people will rightly be viewed as healthy people capable of great mental achievement. And ignorance, in a world ripe with opportunities for learning, will rightly be viewed as a mental disorder. (f) Affirmation: Finally, we need to affirm intelligence research as a "Normal Science", as defined by Kuhn. In my opinion, the founding of this journal and the initiation of this discussion are exactly what needed to happen. Kuhn famously argued that to establish a science, identify the scientific community first, and new paradigms and new researchers will follow.

2. What are the most promising new ideas and approaches in the study of human intelligence?

(a) I may be biased but I think the revival of Thomson's [4] approach to the positive manifold is hands down the most promising new idea in the field (van der Maas, *et al*. 2006 [5]; Bartholomew, Deary, Lawn, 2009 [6]). (b) More sophisticated discourse on the philosophy of latent variables presented a context for the revival of Thomson and a roadmap for future work (Borsboom, *et al*. 2003 [7]; Kievit, *et al*. 2012 [8]). (c) Answering Cronbach's call for the unification of experimental and differential psychology via working memory and intelligence (Engle, Kane, 2004 [9]; Conway, Kovacs, 2013 [10]). (d) Moderated factor analysis and ability differentiation (Molenaar, *et al*. 2010 [11]). (e) Finally, advances in neuroscience methods are obviously exciting. That said, given the expense of some of these techniques and given the complexity of the data, the bonds linking theory, construct, and measurement must not be broken (Gray, Chabris, Braver, 2003 [12]; Burgess, Braver, Conway, Gray, 2011 [13]).

Richard D. Roberts (ETS; E-Mail: RRoberts@ets.org)

Selected issues in the domain of human intelligence that in turn, may lead to new ideas and approaches:

1. The field could make better use of the wide variety of psychometric techniques available to make better inferences using imputation and cross-lagged panel designs. Sample sizes in the 1000s should be the norm in this field, which will allow more powerful analysis. It is great that Paul De Boeck serves as the Editor, since he gets the importance of marrying psychometrics and substantive theory.
2. Carroll [14] did an awesome job summarizing the state-of-the-art in psychometrics by the end of the 1980s, there is a real need to make revisions to his model based on the cumulative body of work

conducted since that time. Indeed, extending the range of first- and second-order constructs within the Cattell-Horn-Carroll model should be a major goal of the field. For example, we still need to resolve how maximal social and emotional abilities fit within this model.

3. Cognitive assessment is still very much beholden to the Army Alpha, it would be great to use new technologies (e.g., games, virtual reality) to create more authentic assessments. For example, with the advent of NLP, constructed response should be the norm in assessment and represents a fertile domain for exploring constructs like creativity that have been delimited by paper-and-pencil scoring.
4. For both research and potential practical applications, it would seem a real need for automatic item generation that is based on substantive theory.
5. The range of outcomes that cognitive ability indicators predict is still not well understood. Solving the criterion problem is essential. There is great potential in using big data to get around this problem.
6. Research is highly beholden to funding agencies. I have noted the following are emerging as hot topics across the globe (and do not have direct links to neuroscience): Team intelligence/problem solving; cross cultural intelligence; creativity; is it possible to develop individual differences measures of cognitive biases. There are probably many more, but having such a list would be helpful for anticipatin research trends.
7. How this field interfaces with applications (policy, labor economics, clinical, neuroscience) -- and promotes itself in so doing -- is going to be vital in the next couple of decades.

Kaarin J. Anstey (The Australian National University; E-Mail: kaarin.anstey@anu.edu.au)

1. What are in your view the most important scientific issues in the domain of human intelligence?

I think the most important scientific issue in the domain of human intelligence is discovering how much intelligence (or cognitive abilities) can be improved or changed through intervention. Recent cognitive training studies have demonstrated improvement in performance of laboratory-based cognitive tests, and changes in brain structure and function. This work is very preliminary and the optimal interventions are unknown, as it the optimal time to intervene, and strength of intervention. As such we do not yet know what the limits of intelligence really are.

A second area of importance for the science underpinning our understanding of intelligence and cognition, is discovering how lifestyle and environment influence cognitive development and abilities. We are learning more and more about how physical activity, smoking, cholesterol levels, toxic exposures and diet are linked with risk of late-life dementia but we do not yet understand the mechanisms underlying these associations.

2. What are the most promising new ideas and approaches in the study of human intelligence?

The most promising approaches involve linking cognitive abilities to their neural substrates using neuroimaging technology. We are learning more and more about the brain and how its characteristics are reflected in intellectual function. This provides the biological basis for theory development.

The most promising ideas in the study of human intelligence relate to neural plasticity. Just how plastic is the brain and cognition? How does plasticity change over the lifecourse? Are some of the disorders we had previously accepted as stable characteristics of individuals now treatable? Finally, can we intervene to prevent cognitive decline in old age?

Tim Croudace (University of York, UK; E-Mail: tim.croudace@york.ac.uk)

It is a selfish but pleasant luxury to be asked to offer one's perspective of critical issues in the domain of human intelligence research. For me the topic and tools of intelligence research are intrinsically linked through the activities I have engaged in as an analyst and investigator in my career to date. My outlook is from that of a non-clinical psychologist interested in how individual differences contribute to population heterogeneity in longitudinal studies of well-being and mental ill-health. My brain "lights up" when I see how constructs are defined and quantified by lower level insights about the stimuli or materials (often items) through which their nature is probed and enumerated i.e. where quantitative values become assigned to individuals based on measurement orientations (Rasch *vs.* IRT) or via other latent structure analysis model variants that convey traitoriented perspectives, as well as define state-specific variation(s). I value studies that combine information from different levels and modes, and currently entertain a passion for combining my emerging understanding about how genetic and environmental factors can be studied with combined perspectives from multidimensional psychometric and mixture models. I expect such models to be required to exploit large scale micro-data that may redefine the actions that define intelligence in "Big Data" sets from real-world activities: e-Social Science data in real-time. The same is true for e-behaviour or e-decisionswhich provide a link to the dynamics of emotion and insight into adjustment too.

The frontiers of modern genetic research challenge us to consider the dynamics of change, and require even greater (collective) scientific and (individual) intellectual effort along with a new respect for studies able to use, combine and relate data from different stages and information sources over the human life-course: from life-course longitudinal research but also from information systems in our education, health and other public services, as well as the rapidly evolving innovations and data capture intrinsic to social media and future communication technologies.

This "modern brand" is promising but challenging, and builds on strengths and depths of insight from many disciplines. Combining enough salient information in any one scientific investigation now requires understanding and sensitivities to the achievements of several highly complex fields. The future champions of intelligence research will define new horizons in "intelligent behavior", probably building on realistically complex core understanding within any one field, but "greeting and joining" with the merits of one or several others at key interfaces for knowledge exchange and combination.

Although it might be possible to link intelligence and personality variation to diagnoses and disorders – a well- trodden route in my own area of expertise - it is well recognized that progress will be more likely if finer grained elements are identified and phenotypic variation that is observable prior to morbid states or syndromes are manifest examined in relation to experience and environment. My critical issue for intelligence research (outside of the brain) is therefore to maintain the integrity of the psychometric implementations through which we capture key variation and can quantify its precision, whilst bringing the same attention to detail to the other sides of the genetic and environmental

equations. It is important (but not my field) to pursue such work in the context of modern neurobiology and social science contributions. These can inform on the substrates and the contexts in which intelligent brain activity is manifest, and recognizable in terms of our existing network of psychological understanding of human trait-like behaviour(s) and repertoire.

Intellectually, I seek an understanding that is of constructs that are intrinsically valid "longitudinally", over the medium and longer term time scales contexts of our ever-lengthening lives, but that is built from ecologically valid micro-data from experiences and decision-making in our daily lives - of (life) course!

Julie Aitken Schermer (The University of Western Ontario, Canada; E-Mail: jharris@uwo.ca)

1. What are in your view the most important scientific issues in the domain of human intelligence?

In my opinion, an important issue in the study of human intelligence is the issue of measurement. As well as the distinction between traditional paper and pencil measures versus biological or reaction time measures, there is the issue of what level of intelligence is being assessed. For example, many of the traditional paper-and-pencil measures of intelligence consist of multiple sub-scales. These scales tend to be aggregated into the creation of verbal and performance scores which are then used to generate a general intelligence (g) score. Many of the subscales provide rich information as to the relationships with other variables, such as personality dimensions or other abilities. The unique variance from these scales should be further investigated to increase our understanding of intelligence.

2. What are the most promising new ideas and approaches in the study of human intelligence?

Intelligence and personality represent two of the most stable psychological characteristics and relationships between these two dimensions is fascinating. In particular, meaningful correlations have been found between personality and intelligence factors at the phenotypic, genetic, and environmental levels. The genetic correlations suggest that some of the observed phenotypic correlations have emerged from common genetic factors. Tests of the Differentiation of Personality by Intelligence hypotheses has also revealed that the structure of personality differs for people at various points along the intelligence continuum. From these research areas, a promising new area is to examine how the two areas develop together through childhood to old age and how personality influences intelligence and how intelligence influences personality.

Roberto Colom (Universidad Autónoma de Madrid, Spain; E-Mail: roberto.colom@uam.es)

1. What are in your view the most important scientific issues in the domain of human intelligence?

The precise measurement of distinguishable cognitive abilities and their organization. Renewed tools are required.

The identification of basic cognitive mechanisms supporting these abilities.

The description of brain features contributing to behavioral differences in standardized situations requiring intelligence.

The discovery of interactions among genetic and non-genetic factors more and less relevant for intelligent performance.

2. What are the most promising new ideas and approaches in the study of human intelligence?

At the end of the day, scientists will find that the analysis of genetic and non-genetic influences would be irrelevant because their interactions are implemented in the brain. All we need is understanding how different brains work.

Novel descriptions of what happens in the brain when facing situations requiring intelligence will be derived from the use of technology developments. The (American) Brain Activity Map Project (BAM) and the (European) Human Brain Project (HBP) will help intelligence researchers to test new ideas and approaches.

The new descriptions will tell that not all brains work the same way for achieving comparable goals. The brain is a general purpose device and it is also highly dynamic. Scientists will describe and characterize 'personalized brains' (individual connectomes equivalent to individual genomes).

Science will find methods for improving our brains by pharmacological/neurological (smart pills/transcranial magnetic stimulation, TMS) and behavioral treatments based on adaptive cognitive challenges that cannot be automated.

Matthias Ziegler (Humboldt-Universität zu Berlin, Germany; E-Mail: zieglema@hu-berlin.de)

1. What are in your view the most important scientific issues in the domain of human intelligence?

Assessing intelligence and its components as described in different models (e.g., CHC) using standardized tests has come a long way. The measures yield scores that are reliable and maybe even more important interpretations of the scores have impressing validities in a wide array of everyday life criteria. However, the hierarchical and facetted structure of the test needs to be mapped onto the brain. First attempts have been made. Yet, interindividual differences in brains are so far neglected except for size and volume *etc*. Interindividual differences are the driving force behind the success of standardized tests. It will be a challenge to determine whether size related interindividual differences are sufficient to explain interindividual differences in test performance.

2. What are the most promising new ideas and approaches in the study of human intelligence?

Human behavior and feelings are determined by a multitude of different personality characteristics. Intelligence certainly is an important aspect here. Nevertheless, models explaining human behavior need to include more than just intelligence. So far intelligence research and research on noncognitive traits has only few interconnections. Most studies trying to explain human behavior either use only variables from one of the two areas or look at additive effects. Recently, there are a few studies that try to shed light on interaction effects between intelligence and noncognitive traits. These studies have great potential in my view.

Successful or sustainable aging is an important issue in our society. Longitudinal studies investigating the aging effect not only for intelligence but again also for other personality traits will help to understand interindividual differences in aging. This way it will be possible to identify the

actual mechanisms underlying development of intelligence (and noncognitive traits) and relationships between these developments. Both will help us understand how successful aging can be fostered.

Jeremy R. Gray (Michigan State University; E-Mail: grayjer2@msu.edu)

1. What are in your view the most important scientific issues in the domain of human intelligence?

What does "intelligence" mean, and what should it mean? a) What is its relation to all aspects of social competence (including but not limited to theory of mind, and expressive and receptive communicative abilities)? Other humans seem likely to have been one of several major sources of selection pressure driving the evolution of intelligence. b) What is the relation of intelligence to implicit learning and related forms of cognition (e.g., Kahneman's System 1)? This is a very pervasive and important skill (or set of skills) in both humans and animals but rarely assessed in formal intelligence batteries. c) What is the relation between intelligence and creativity? The two constructs are widely regarded as related yet distinct.

How does human intelligence work, mechanistically? A complete understanding will require developing and integrating models at multiple levels of analysis, including genetic, gene x environment, neural substrates, and information processing (cognitive-level).

2. What are the most promising new ideas and approaches in the study of human intelligence?

Large-sample brain imaging and whole-genome studies are increasingly feasible (several thousand participants minimum). Such sample sizes combined with "big data" methods will be useful and likely essential, given the weak contribution of a large number of genes and gene-gene interactions.

Large-sample studies will be truly informative if they assess the right psychological phenotypes, and so it is essential to have as complete a conceptual picture as possible, including social ability, implicit learning, and creativity

Con Stough (Centre for Human Psychopharmacology; Swinburne University, Melbourne, Australia; E-Mail: cstough@gmail.com)

There are many critical issues relevant to intelligence research and its applications. I`ll describe my own personal thoughts which I`ve tried to translate into empirical studies and grad student supervision over the last 20 years.

My greatest interest is in understanding biological differences in cognition and intelligence as well as individual differences in these constructs. There are two main typical ways to better understand the biological basis of human intelligence: neuiroimaging and pharmacology Although the structure of the human brain is of great interest (neuroimaging) my emphasis has been to study what happens within the synapse. This approach has been to examine how various drugs, neurotransmitters, nutrients, chemicals, anti-oxidants and even vitamins affect cognitive performance. What are the key neurotransmitters that underpin human intelligence? Which receptors are responsible for performance across different cognitive domains? Can we ameliorate cognitive decline with pharmacologically active substances and if so what mechanisms underpin these cognitive changes? Can we develop drugs that acutely or chronically improve intelligence and if so which mechanisms (neurotransmitter, anti-

oxidant, inflammation, blood flow *etc.*) underpin these changes. Some of our most recent studies are highlighting the role of the cardiovascular system in cognitive changes. Therefore there are also opportunities to improve cardiovascular function pharmacologically which may have an important role in improving cognition. There are differences in drugs that improve cognition acutely and chronically. Acute cognitive enhancers such as Modafinil improve alertness and increase attentional networks. However there may be chronic acting drugs ie drugs that do not have an obvious immediate action but exert their effects cumulatively over time. These latter classes may be beneficial in preventing cognitive decline or even disorders of cognition with age such as dementia.

The last point I want to make is that I don't see the value of behavioural genetic work. Intelligence will always be the interplay between nature and nurture (genes and environments). Understanding genes in isolation to our environment is likely to not be very useful or helpful. So gene-environment interactions will be important for future research. Translating that premise to my work, we would be interested in understanding how the environment changes receptor density and changes in neurotransmitter activity.

Scott Barry Kaufman (New York University; E-Mail: sbk334@nyu.edu)

The most important scientific (and conceptual) issues in the domain of human intelligence:

An open discussion about what "intelligence" really is, and whether it can ever be measured in a static way.

Investigation of the relations between novel, goal-directed problem solving and the efficient and complex intelligence of the cognitive unconscious (e.g., implicit learning, daydreaming, latent inhibition, *etc*.).

The development of a broader array of implicit learning tasks that are suitable to the investigation of individual differences, are ecologically valid, and predict important academic and societal outcomes above and beyond the effects of general cognitive ability and the cognitive mechanisms underlying general cognitive ability.

Further understanding of the complex interplay of nature and nurture influencing the manifestations of general cognitive ability, differential developmental trajectories for the acquisition of such skills, and the different behavioral, neural, and genetic pathways to such manifestations.

Greater appreciation and understanding of the intelligence of the spontaneous cognitive processes associated with the default mode network.

Scientific study of the differential role of the competencies captured by general cognitive ability and specific cognitive abilities and talents (e.g., artistic, music) across many different forms of creative achievement, from the arts to sciences to business to social entrereneurship to sports.

Tighter integration between the g approach and both the expert performance approach and the self-regulated learning strategies approach.

Tighter integration between the g approach and the latest research on motivation, mindset, and self-regulation.

Scientific investigation of the characteristics most predictive of long-term engagement in a domain and the attainment of one's personal goals.

Ultimately, I'd like to see the field embrace a broadened conceptualization of human intelligence that goes beyond performance on any standardized test measured one moment in time, and which expands the time scale from performance in a single decontextualized testing session to a lifelong growth mindset of deeply personal learning, problem solving, and overcoming obstacles.

Paul De Boeck (The Ohio State University; E-Mail: deboeck.2@osu.edu)

1. What are in your view the most important scientific issues in the domain of human intelligence?

Four aspects: Cognitive performances have four aspects: 1. the level of performance, 2. underlying processes at different levels: cognitive processes, brain processes, chemical processes; 3. the infrastructure of the processes, cognitive structures and brain structures and systems; 4. individual differences in 1, 2, and 3. Ideally, the four aspects are studied at the same time. Most likely, the individual differences referring to 2 and 3 cannot be captured in separate variables with linear relationships, but rather as variables of a dynamic system that operates in a structure with some degree of plasticity. Also the degree of plasticity and the types of plasticity can show individual differences.

Definition: A definition of intelligence is perhaps useless. All we can do is to give a broad and vague indication of the domains of cognitive performance where to look for processes, relevant cognitive and brain structures and systems, and for individual differences. With a sharp delineation we run the risk that we miss important aspects. A possible definition of intelligence should not say what the nature of intelligence is. The nature is the nature of the processes and structures still to be discovered as underlying the performances in the vaguely indicated domains. At best a definition is a vague indication of where to look. A better definition follows the findings, it does not precede empirical studies. A definition is an end point, not a starting point.

Individual differences: Individual difference measures of intelligence do have high practical value (for prediction, for decision making, *etc*.), but, until we also understand better to which processes and structures these differences refer, the individual difference measures do not lead us to a further understanding. The domain of intelligence is dominated by the study of individual differences whereas general cognitive psychology and cognitive science are as relevant, and certain domains of neuroscience and biological psychology as well also when not studying individual differences, while the combination and integration of these approaches is the optimal way to go.

Unresolved issues: Some old issues are unresolved. They appear now and then in the literature, but without a good solution, in order to be forgotten again. One example is the speed-accuracy-tradeoff in cognitive performance task. Another, perhaps related example is the power *vs.* speed issue. A third example is that we still don't have a good way to isolate the effect of secondary factors such as test anxiety, persistence, motivation, *etc*. This is perhaps because of the continuous space of variables and the intrinsic nature of the relatedness in that space.

Psychometrics: Psychometrics and quantitative approaches in general can help the field with at least a few tools, not so much to improve measurement as one may think, but to test theories and find out what the nature of phenomena is. Psychometrics and quantitative models do of course help for measurement, but there is more they can do. One example g. Is g an identifiable individual-differences concept? The crucial test would be a test of bifactor model assumption, not just applying the bifactor

model. The crucial assumption of the model is that all inter-item correlations between domains of cognitive performance (verbal, visual, *etc*.) have only one source. Inter-item correlations within domains can have one (or more) additional sources. The one source of inter-item correlation between domains would be g. If the one-source condition for item correlations between domains is not fulfilled, g cannot be identified and will be influenced by the tests included in the analysis. If the bifactor condition applies, the general factor does not vary depending on the tests in the study.

Another example is the nature of Flynn effect. The studies are inspiring thus far and do generate highly interesting explanations, but a more fine-grained quantitative approach can perhaps help to find out the more precise nature of the phenomenon so that it would be easier to find a good explanation.

2. What are the most promising new ideas and approaches in the study of human intelligence?

Functional and structural studies of the brain
Brain plasticity
Studies of the biochemistry of brain connections

The growing interest in individual differences in cognitive psychology and cognitive science, and biological psychology relevant for the field of intelligence

Methodological approaches for the Flynn effect
Intelligence and aging
Autistic intelligence

Oliver Wilhelm (University Ulm; E-Mail: oliver.wilhelm@uni-ulm.de)

1. What are in your view the most important scientific issues in the domain of human intelligence?

Intelligence is an opaque term. The measurement procedures that can be subsumed under that term are psychology's biggest successes, but our theoretical understanding of intelligence is still in its infancy. The first important issue is intelligence research has been separated from efforts to study decontextualized approaches to human cognitive abilities. This was a mistake and its correction is an important issue.

Frequently, it is hard to see how empirical work in intelligence research truly adds to our theoretical understanding of intelligent information processing and helps produce cumulative progress. Thus, the second issue is the field could be improved by conceptually strengthening research designs so that intelligence research is more strongly connected with related areas of psychology – most importantly cognitive psychology.

Unlike other areas of psychology, progress in intelligence research was closely related with progress in statistical methods, but this relation became weaker in the last two decades. For example, methods to simultaneously study means and covariances are rarely applied in intelligence research. Similarly, sophisticated modeling of change is still not adequately appreciated. Main stream textbooks and publications in leading journals no longer center on methodological progress and innovations. Therefore, a third issue is to stress and ensure the methodological quality of intelligence research.

The fourth important issue within intelligence research, which has been intensely investigated in the last two decades, is interpersonal abilities. The enrichment of traditional intelligence research needs to be embedded within the intelligence structure. Maintaining and strengthening the close relationship of this research branch with basic research, for example in the area of emotion, is critical for long term success.

The fifth issue is about the actual application of these tests. Intelligence tests by and large look as they did 100 years ago. Innovations in the area of new constructs have not been adequately cherished in the past, although further success of the field hinges on the success of such novel approaches. Novel assessment procedures for example in the area of productive abilities, such as expressive writing or emotion expression, deserves more attention and consideration.

2. What are the most promising new ideas and approaches in the study of human intelligence?

The first promising approach is integrating research on mean differences within and between groups, individual differences, and change over time. This integration will help overcome the tendency to study only individual differences in intelligence while neglecting intraindividual change and (quasi-) experimental aspects.

A second intriguing development is related to studying genetic aspects of intelligence. Although currently the success in accounting for individual differences in maximal cognitive effort through individual differences in genes is very limited, genetic methodologies are developing rapidly and it is to be expected that the genetic basis of intelligence will be established eventually. In related fields, like Neurology, the genetic basis of many disorders has been established and it is likely that more complex traits, like intelligence, will follow in a decade or so.

A third promising idea is research directed towards studying the malleability of intelligence. Currently, adequate research designs are more an exception than the rule, but this is certain to change.

b) Editorial Board Discussion: Second Round Contributions

Con Stough

I would like to comment on some posts but mainly agree with the posts of Matthias Ziegler. I agree that the structure of intelligence has seen remarkable gains over the last 20 years and I like the framework that the CHC model provides. Unfortunately comprehensive frameworks of cognitive abilities and processes are often missed by biological researchers in their studies (including myself). In drug studies on cognition and intelligence we use computerised cognitive tests which are at best ad-hoc in their interpretation of the full CHC factors. Some of the developers of computerised cognitive assessments (e.g., the CANTAB) are not even aware of the CHC framework. Likewise in neuroimaging studies we use cognitve tests that are easy to administer in MRI or other machines. Until we can better operationalise the CHC factors into tasks that can be utilized in experimental research our understanding of the the biological basis (pharmacology, connectivity and structure) of intelligence will be limited.

On another topic not much has been discussed about the interface between cognition and emotions in this dialogue. I am wondering why this is? Is there a collective view that emotions are not

important, too hard to measure or simply a lack of interest? This thought might be provocative for some researchers.

Andrew R. A. Conway

Before I comment I feel like a disclaimer is in order. So, disclaimer: I've collaborated with both Jeremy Gray and Oliver Wilhelm, and so, not surprisingly, I agree with almost everything they wrote! I will therefore address my comments in this round to one of the other contributors, namely, Scott Barry Kaufman.

Scott, as you know, I admire your work and I found your opening statement just perfect: "An open discussion about what "intelligence" really is." In that spirit, I'm curious to hear your thoughts about the relationship between implicit learning and general cognitive ability. You call for "The development of a broader array of implicit learning tasks that are suitable to the investigation of individual differences, are ecologically valid, and predict important academic and societal outcomes above and beyond the effects of general cognitive ability and the cognitive mechanisms underlying general cognitive ability." It's not clear to me if we should consider implicit learning as falling under the umbrella of "intelligence" or separate from it. How do you view this relationship?

Scott Barry Kaufman

Here's my response to Conway:

Great question Andy. In recent years I have been arguing for the need to incorporate spontaneous cognitive processes (e.g., implicit learning, reduced latent inhibition) under the umbrella of "intelligence", even if all of the cognitive processes aren't strongly correlated with each other. I wish the field would break away from the notion that a test only measures "intelligence" to the extent that it loads highly on g. I think that's a very limited view of intelligence and has stunted the field. I think it's more important to look at what intellectual behavior is being predicted, and have a broader consideration of the relative balance of explicit/implicit forms of cognition that are most predictive of that specific behavior.

Here's my commentary on Matthias Ziegler:

Ziegler says:

"Assessing intelligence and its components as described in different models (e.g., CHC) using standardized tests has come a long way. The measures yield scores that are reliable and maybe even more important interpretations of the scores have impressing validities in a wide array of everyday life criteria. However, the hierarchical and facetted structure of the test needs to be mapped onto the brain. First attempts have been made. Yet, interindividual differences in brains are so far neglected except for size and volume *etc*. Interindividual differences are the driving force behind the success of standardized tests. It will be a challenge to determine whether size related interindividual differences are sufficient to explain interindividual differences in test performance."

I agree it's important to see how the different CHC factors are related to actual brain processing. But why must the field continue to rely so heavily on interindividual differences? There are some exciting new techniques looking at intraindividual differences, which takes into account the fact that every individual is a dynamic system of cognition, affect, and personality. Importantly, the results of the intraindividual differences approach don't apply at the interindividual differences level of analysis, and vice-versa. I think the field of intelligence has done a great job categorizing the various sources of variability in performance on tests of cognitive ability, but it's really time to move beyond that approach to understand the full complexity and richness of human intelligence.

Andrew R. A. Conway

Scott, thanks for addressing my question. I now have a better understanding of where you're coming from and I think it's an interesting approach. I also second your response to Ziegler about the importance of intra-individual differences. As we start to incorporate data from neuroscience I think this will become even more important.

In response to De Boeck and Colom, I think many of your criticisms are fair and I see your point in most cases but your arguments that construct validity and definitions aren't important are hard for me to wrap my head around. Yes, the definition of a construct is largely semantic but the validation of a construct is not. De Boeck, we are in complete agreement about emotional intelligence. That is exactly why I argue for the importance of valid constructs. We can't continue to just make them up out of thin air. Finally, in response to Colom, I did not argue that all researchers must integrate across levels of analysis. I simply argued that we should all embrace the fact that there are different levels of analysis and appreciate that different programs of research have different goals. For example, at the neural level, we may want to investigate whether connectivity between two brain regions is related to behavioral performance. But at the societal, say educational level, we may be more interested in which tasks/tests predict academic achievement.

Matthias Ziegler

Here is just a quick answer to Scott Barry Kaufman's comment to my previous post:

I fully agree that the scientific advances that you mentioned are a huge step forward and possibly a promising paradigm shift. I also agree that the field should move on. However, I would be happy if research would also address the questions left unanswered regarding interindividual differences. In the end, as was often the case in psychology, the combination of different approaches might allow a more complete view on this complex phenomenon.

Paul De Boeck

The following two comments are formulated to be controversial, in too extreme a way, in the first place for the purpose of the discussion, but also because I believe there is at least some truth in the remarks. The ideal would be a good balance. I am focusing on one side of the coin. It is of course not as black versus white as I suggest with my remarks.

1. I would not care about a definition of intelligence, I don't care about what intelligence really means. Scientific progress does not come from definitions but from findings. I would rather study phenomena and regularities in the data and wait with definitions. Construct validity is not really important. We do not start with constructs, we end with constructs, the constructs we need to explain the data. We have far too many constructs in psychology, including the domain of intelligence. Constructs come and go and they have not helped us much when it comes to understanding. For example, does it help us understand anything when we include emotional intelligence in the construct of intelligence compared with when we don't? It is rather a semantic discussion how we define a construct. Until we would know how things work. Take analogy problems as another example. What is the surplus of considering these tasks as indicators of intelligence, of inductive intelligence? Let us rather find out how people solve analogy tasks and what the related brain processes are. Are these the same or how much are they related with other cognitive tasks? *Etc*. I don't mean related in the correlational sense. The nature of the processes is more important. Correlations are fine but should not dominate the field.
2. The psychometrics of intelligence tests and intelligence research is somewhat behind compared with personality and clinical. That is somewhat surprising. I did a study on IRT for psychological tests and it appears that it is mainly used for personality and clinical tests. This remark may seem to contradict my previous remark because IRT is primarily seen as a measurement tool, to measure constructs. I would in fact be more interested in non-measurement uses of IRT, it would be IRT for understanding how respondents come to a correct response or why they fail. That is perfectly possible, since IRT means that the item responses are modeled, as a function of .. and here we have the freedom. We happen to fill that in with individual differences, but that is not the only possibility. Measurement has in the first place a practical purpose, until we know what we are measuring. Measurement is a spin-off of understanding how something works. Measurement does not come first, it comes after. We still don't know yet what we are measuring, all we know is that the measurement has predictive value. Measurement in itself will not help much when it comes to finding out what the cognitive and brain processes are. And that is where to look to find out eventually about something we may want to call intelligence after all (and give a definition) or perhaps we may want to call it differently.

Roberto Colom

The limits between science and science-fiction become thin when we researchers are kindly invited to speak about a topic of our interest. This is particularly true for the intelligence construct and not necessarily a bad thing.

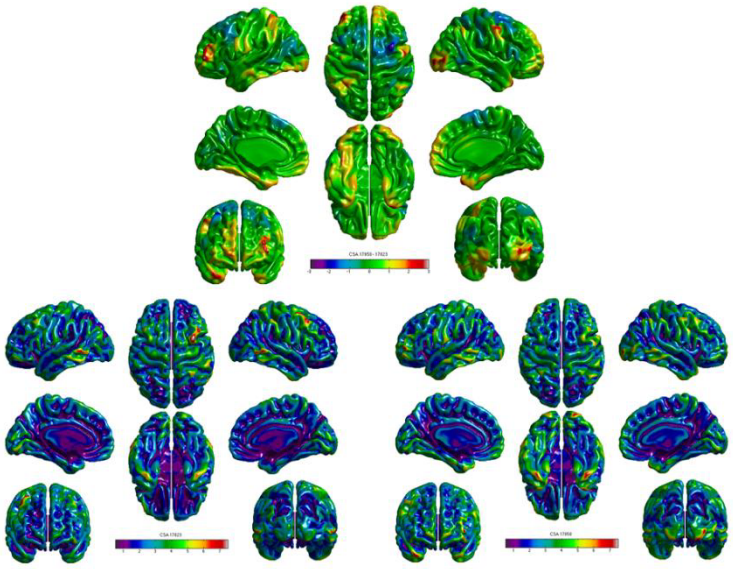
For the sake of the discussion I constructively disagree with several points comprised in these pages. Examples: the definition of intelligence, the integration of levels of analysis, the coordination of intelligence and personality traits, the crucial status of longitudinal research, the relevance of learning, or the relevance of creativity.

As noted by De Boeck, definitions are not that important. Science needs reliable data and this information must be as straightforward as possible. Underscoring that we must pay integrate distinguishable levels of analysis sounds great, but this requirement introduces too many complexities.

Researchers already have tried to relate intelligence and personality, but they failed. Longitudinal studies enjoy a great appeal, but we know that it is extremely difficult to find stable parameters across time (there is a lot of randomness) beyond those attributable to the individual. The causal chain goes from intelligence to learning, so it might be useless to make questions about the role of learning. The same applies to creativity.

In my view, we are urged to embrace greatly simplified frameworks. Brave simple-minded hypotheses are wanted. Let's focus on the brain and how everything out there is organized 'indoors' to produce intelligence. Intelligence is a psychological trait crucial for understanding human behavior, because it integrates many others (including learning, creativity, or personality). Intelligence is like the sun and the remaining psychological traits describe orbits around. Some are closer than others. Many are far away.

I'm suggesting that we need very simple versions of this presumably complex problem called 'intelligence'. Interesting individual differences in intelligent behavior are produced by different brains. The same intelligence is produced by different brains (see figure).



Bottom panel: distribution of cortical surface area values across the brain for two young human beings (A, left and B, right) with exactly the same scores in fluid, crystallized, and visuospatial intelligence. Top panel: differences between A and B in the distribution of cortical surface area. There is, for instance, a substantial difference in the left frontal lobe, but this is not leading to any difference in Gf, Gc, or Gv.

We must understand how different brains actually work to 'exude' intelligence. As noted in my contribution, European and North-American scientists are currently integrating efforts to this end. We must join them and stop saying that there are many interesting things under the stars deserving a close scrutiny. This is true, but not really useful.

Julie Aitken Schermer

Reply to Dr. Kaarin J. Anstey

I was very intrigued by Dr. Anstey's posting with respect to the improvement of intelligence through nutrition (a similar statement put forth by Dr. Con Stough). With respect to behavior genetics and twin studies, I have always been intrigued as to what some of the unique environmental influences could be to make MZ twins different in their cognitive ability scores. If the unique environment (what one twin experiences that the other twin does not experience plus measurement error) accounts for about 50% of the variance in intelligence scores, then it would be interesting to discover what accounts for some of that variance. Although this would be a challenging area of research, I think it would be quite enlightening. Thank you to all for the interesting comments.

Jeremy R. Gray

Unless I missed it, no one mentioned engineering/simulated/artificial approaches to intelligence. For the most part, such approaches have been underwhelming to date. However, it is also the case that for intelligence to thrive as a research domain, better psychometrics, genetics, brain imaging, and interventions (from education to pharmacology) will not be enough. We will need causal, mechanistic models of how humans actually produce intelligent behavior. It seems likely that these models can both inform and be informed by engineering approaches to intelligence. So efforts to promote dialog are likely to be challenging in the short term at least, but potentially highly profitable long-term.

References

1. Sternberg, R.J.; Detterman, D.K.; Eds. *What is Intelligence?* Ablex: Norwood, NJ, USA, 1986.
2. Intelligence and its measurement – a symposium. *J. Educ. Psychol.* **1921**, *12*, 123–133.
3. Marr, D. *Vision*; Freeman: San Francisco, USA, 1982.
4. Thomson, G.H. A hierarchy without a general factor. *Brit. J. Psychol.* **1916**, *8*, 271-281.
5. van der Maas, H.L.J.; Dolan, C.V.; Grasman, R.P.; Wicherts, J.M.; Huizenga, H.M.; Raijmakers, M.E. A dynamical model of general intelligence: The positive manifold of intelligence by mutualism. *Psychol. Rev.* **2006**, *113*, 842–861.
6. Bartholomew, D.J.; Deary, I.J.; Lawn, M. A new lease of life for Thomson's bonds model of intelligence. Psychol. *Rev.* **2009**, *116*, 567–579.
7. Borsboom, D.; Mellenbergh, G.J.; van Heerden, J. The theoretical status of latent variables. *Psychol. Rev.* **2003**, *110*, 203–219.
8. Kievit, R.A.; van Rooijena, H.; Wichertsa, J.M.; Waldorpa, L.J.; Kanb, K.-J.; Scholtea, H.S.; Borsbooma, D. Intelligence and the brain: A model-based approach. *Cognitive Neurosci.* **2012**, *3*, 89–97.
9. Engle, R.W.; Kane, M.J. Executive attention, working memory capacity, and a two-factor theory of cognitive control. In *The Psychology of Learning and Motivation*; Ross, B. (Ed.); Academic Press: New York, USA, 2004; pp. 145–199.

10. Conway, A.R.A.; Kovacs, K. A Process Overlap Theory of the Positive Manifold: A Working Memory Approach. Presented at the 18th Meeting of the European Society of Cognitive Psychology, Budapest, Hungary, 29 August–1 September 2013.
11. Molenaar, D.; Dolan, C.V.; Wicherts, J.M.; van der Maas, H.L.J. Modeling differentiation of cognitive abilities within the higher-order factor model using moderated factor analysis. *Intelligence* **2010**, *38*, 611-624.
12. Gray, J.R.; Chabris, C.F.; Braver, T.S. Neural mechanisms of general intelligence. *Nat. Neurosci.* **2003**, *6*, 316-322.
13. Burgess, G.C.; Braver, T.S.; Conway, A.R.A.; Gray, J.R. Neural mechanisms of interference control underlie the relationships between fluid intelligence and working memory span. *J. Exp. Psychol. Gen.* **2011**, *140*, 674-692.
14. Carroll, J.B. *Human Cognitive Abilities: A Survey of Factor-analytic Studies.* Cambridge University Press: New York, USA, 1993.

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