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A new beginning of intelligence research. Designing the playground

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ABSTRACT

Here we present several points for designing a probable playground concerning a new beginning of intelligence research within the XXI Century: the nature, definition, and measurement of the construct of interest, its development across the lifespan, its enhancement by varied means, and its place within the already identified human psychological traits. Predictions can go wrong when those who make them 1) assume that trends will be linear, 2) use script-writing assuming that they know what the responses to any trend will be, and 3) conflate primary facts with their interpretation. With these pitfalls in mind, we predict: 1) a proliferation of alternate models of the positive manifold; 2) The derailment of the field in the next decade or two with a new trendy research angle; 3) The gradual abandonment of classic IQ tests for intelligence research in favor of alternative measurements. We see a bright future for intelligence research, but dark spots cannot be discarded.

1. Preamble

There is little better way to make reasonable people look foolish than to ask them to predict the future. Consider these five examples:

1903: “The horse is here to stay, but the automobile is only a novelty – a fad.” — President of the Michigan Savings Bank advising Henry Ford's lawyer, Horace Rackham, not to invest in the Ford Motor Company.

1946: “Television won't be able to hold on to any market it captures after the first six months. People will soon get tired of staring at a plywood box every night.” — Darryl Zanuck, 20th Century Fox.

1961: “There is practically no chance communications space satellites will be used to provide better telephone, telegraph, television or radio service inside the United States.” — T.A.M. Craven, Federal Communications Commission (FCC) commissioner.

1995: “I predict the Internet will soon go spectacularly supernova and in 1996 catastrophically collapse.” — Robert Metcalfe, founder of 3Com.

2004: “Two years from now, spam will be solved.” – Bill Gates, founder of Microsoft.

If we think we scientists are immune to such misguided predictions, then consider:

1895: “Heavier-than-air flying machines are impossible.” –Lord Kelvin, British mathematician and physicist, president of the British Royal Society.

1912: “The coming of the wireless era will make war impossible, because it will make war ridiculous.” Guglielmo Marconi.

1932: “There is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will.” Albert Einstein.

1949: “It would appear we have reached the limits of what it is possible to achieve with computer technology, although one should be careful with such statements; they tend to sound pretty silly in five years.” Computer scientist John von Neumann.

1956: “Space travel is utter bilge.” Dr. Richard van der Reit Wooley, Astronomer Royal, space advisor to the British government.

It is deceptively easy to think: “yes, but *I* won't make such silly predictions”, which would likely be the outcome of the myside bias of cognitive bias research (where we believe ourselves immune to common cognitive biases; Stanovich, West, & Toplak, 2013). So, before adding our own predictions to such a list, we suggest three reasons *why* predictions can go so wrong: 1) Linearly projecting trends, 2) Script-writing, and 3) Confusing primary facts with their interpretation.

Linearly projecting trends involves seeing current trends as extending indefinitely into the future on the same trajectories. This is the ‘good times will never end’ belief that can accompany times just before collapse, an example of the recency bias (e.g. Hogarth & Makridakis, 1981). One example could be the expansion of Genome Wide

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Association Studies, being argued as an area of constant growth (Plomin, 2018). Another example involves world population growth. As described by Hans Rosling (2018) Melinda and Bill Gates have been investing billions in primary health and education for saving children living in extreme poverty. They routinely receive, however, messages at their foundation claiming this will contribute to killing the planet because these actions stimulate overpopulation. When parents expect their children to survive, however, their key motivation for having big families vanishes. This linear projection trend is even considered an 'instinct' of our mind that we humans must learn to manage properly (Rosling, 2018). Therefore, predictions can go terribly wrong when assuming a linear trend will continue into the future. Let us not make this mistake.

Script-writing involves projecting exactly what will happen into the future, then predicting exactly what the response will be, then what the response to the response will be, and so on and so forth. Script writing in science can look like the following: "First, we will show that the multiple demand system is in fact isomorphic with the neural networks for intelligence. Then, research will start to merge the neuroscience of intelligence and the neuroscience of the default mode network. Then, we will see stunning overlaps between neural activity at even smaller voxels, isolating the overlap of these major brain networks. Then…" Such script-writing both presumes how research findings will play out, how people will respond to it, and ignores rare events that might derail a scientific field (Taleb, 2007). A new sub-area of research may capture much attention in a given field for a decade or two before being either assimilated or discarded. Thus, for instance, the 2010s were overtaken by new trends in cognitive training (starting with Jaeggi et al.'s famous 2008 article). The 2000s overtaken by single candidate genome studies. We do not know what the next study or subfield will be that pops up to derail a field (for better or worse) in the decades to come, although this *will* certainly happen. Psychology is especially afflicted by this malady. When making predictions, let us not script-write.

Finally, confusing primary facts with their interpretation is perhaps the most insidious problem in forecasting matters. Primary facts are findings or phenomena with minimal model-based interpretation overlaid (Woodward, 1989). Interpretations of those facts are our model-based inferences of the meaning of the primary facts. Consider this prediction from silent-movie star Charlie Chaplin: "The cinema is little more than a fad. It's canned drama. What audiences really want to see is flesh and blood on the stage." (Chaplin, 1916; quoted in Robinson, 1983, p. 20). The primary facts that Chaplin were correct about were that people want to be entertained, and that they want to see is flesh and blood on the stage. The interpretation he confused was that flesh and blood on the stage is the primary way people will not only want to be entertained, but also what the one the largest number of people would want.

In intelligence research, as in other scientific disciplines, it is easy to detect conflation of primary facts with interpretations. *Intelligence* (the general factor of intelligence, *g*) is a perfect instance of such conflation. General intelligence is not the primary fact of mainstream intelligence research; the primary fact is the positive manifold (Carroll, 1993; Haier & Colom, 2021; Hunt, 2011a; Jensen, 1998; Spearman, 1904; Warne & Burningham, 2019). General intelligence is but one interpretation of that primary fact. Making predictions based on the interpretation, instead of on the primary fact, can lead into highly slippery territory. Therefore, let us be clear about primary facts and not interpretations when making predictions.

2. A brief look back before guessing what is coming

Three decades ago, Richard J. Haier (1990) published an editorial (The end of intelligence research) for the journal *Intelligence* asking, "what will we know at the end of intelligence research?" His perspective was oriented towards neuroscience because "sooner or later, all psychology research leads into the human brain." This fits Hunt's (2011a) acknowledgement two decades later: "Ultimately everything is in the brain (…) every expression of intelligence is due to actions of the brain (…) if we knew the nature of every connection between the approx. five billion neurons in a person's brain, and if we knew the algorithms the brain uses to activate and alter these connections, we would know everything there is to know about that person's cognition". Haier visualized international consortiums aimed at searching for brain mechanisms relevant to intelligence. There have been some faint calls and attempts to pursue this goal (Colom, 2014; Santarnecchi et al., 2018) but with limited success so far.

Just months before Haier's, 1990 article, Douglas K. Detterman (1989) also published an editorial (The future of intelligence research) in the same journal beginning with a sort of joke that may help to understand the lack of joint efforts: "in the social sciences, we stand on our predecessors faces rather than their shoulders." Detterman, then editor of this journal, made the following suggestions regarding the future of intelligence research: (1) increase sample size in research studies to a bare minimum of $N = 100$, (2) compute and report corrected correlations for achieving meaningful comparisons across studies ("it makes no sense to confuse the literature with uncorrected correlations that really mean the same thing when corrected"), (3) compute and report reliability values of the considered measures, (4) improve the quality of available theories ("there are many theories that border on armchair philosophy or worse"), and (related with the previous point) (5) consistency between biological and behavioral evidence must be mandatory for reducing "the degrees of freedom the theory maker has available."

Both editorials converge regarding the relevance of the brain for refining our knowledge regarding human intelligence. Detterman (1989) wrote: "understanding of human intelligence will not be complete without knowing at least something about how the brain works." And, perhaps predicting skeptic reactions from identifiable bands within the scientific community, Haier (1990) explained that "the search for brain mechanisms that are relevant to intelligence is no more reductionistic than a search for cultural or social mechanisms."

A quarter of a century later, a new journal devoted to the intelligence construct was born (*Journal of Intelligence*) and the first issue (Intelligence, Where to Look, Where to Go) was aimed at discussing about the future of intelligence research (De Boeck, 2013; Hunt & Jaeggi, 2013; Johnson, 2013). One of us participated on the issue endorsing a neuroscience approach: "the limits between science and science-fiction become thin when we researchers are invited to speak about a topic of our interest (…) 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. We need very simple versions of this presumably complex problem called 'intelligence' (…) we must stop saying that there are many interesting things under the stars deserving a close scrutiny. This is true, but not really useful." (Colom, 2013).

Albeit suggestive, all this belongs to the past. Now we are invited by the current editor of this journal to predict the future, which is a big challenge. Next is our tentative forecast aimed at contributing to the design of the playground for a new beginning of intelligence research within this century. The playground comprises five pillars: (1) the interpretation and nature of intelligence, (2) the measurement of intelligence, (3) intelligence unfolding across the life span, (4) the engineering of the intelligence of humans, and (5) the integration between intelligence and other psychological traits. Throughout, we will (try to) be mindful to not descend into linear predictions or script-writing. We also try to not conflate what we *think* will happen with what we *want* to happen. Finally, we will also aim to focus on primary facts instead of on interpretations of these facts. Far from easy.

3. The interpretation and nature of human intelligence

3.1. Interpretation

First, and foremost, without the positive manifold (the positive correlation among measures of varied mental abilities), there is no (general) intelligence. There is an indisputable positive manifold (the fact), but there are several interpretations (the models and theories).

For generations, a hierarchical model of some sort has stood as the dominant interpretation of the primary fact of the positive manifold (Spearman, CHC). But in recent years, new contenders continue to arise. We suspect the status of a hierarchical model was questioned by three findings. The first was the publication of the Dickens & Flynn model of feedback mechanisms (Dickens & Flynn, 2001). This introduced multiplier models that eventually have led to dynamic mutualism (van der Maas et al., 2006), another interpretation of the positive manifold. Next, showing that a sampling model (Thomson, 1951) provided equally good fit as a hierarchical model (Bartholomew, Deary, & Lawn, 2009) revealed the hierarchical model cannot be accepted on only statistical model fit grounds. This has led to additional sampling-type models (e.g. POT, Kovacs & Conway, 2016). Finally, the expansion of network models, complete with their increased ease of access via open-source software, has shown a new way to interpret a correlation matrix comprised by cognitive and intelligence measures (e.g. Cramer et al., 2016). Thus, the positive manifold can increasingly be interpreted as a network model (Barbey, 2018; Schank, Goring, Kovacs, & Conway, 2019).

These sorts of models provide new interpretations of the positive manifold. They are statistically sound, and in some cases provide an equivalent fit to a hierarchical model (sometimes better, sometimes worse), thus damaging belief in the dominant hierarchical model.

In these situations, a possible course of action would be the proliferation of multiple competing theories, instead of shifting to a new favored interpretation. When a dominant interpretation falls out of favor, a proliferation of new theories can flood the marketplace. As the incentive structure of early 21st century science is that researchers create their own theories instead of using someone else's (e.g. Mischel, 2008), the most likely prediction would be, for better or worse, that we will see a proliferation of new interpretations of the positive manifold.

Ideally, we foresee researchers testing models against one another in an attempt to falsify them, involving pre-registered predictions and adversarial collaborations. Nevertheless, such a hope is unlikely, because the incentive structure in academia is to have a pet theory that one is famous for and only pursue confirmatory evidence for that theory (see also Scheel, Tiokhin, Isager, & Lakens, 2020). This being the case, and in the absence of strong external pressure (like that was done for research on Consciousness: see Reardon, 2019), we will likely see many new publications extolling how an alternate model of intelligence, not requiring factor analysis, is supported by additional data. As noted by E. B. Hunt (2011a) sometimes scientists rely on practices resembling “the behavior of a lawyer presenting the evidence for a client rather than the behavior of a scientist reporting data to be considered in evaluating theories.” This is not a judgment, as theories need to be reviewed and revised continually.

3.2. Nature

Regarding the nature of intelligence, we are far beyond the mystical mental energy idea (Geary, 2019; Lykken, 2005; Matzel et al., 2020) and still far from a foundational understanding of what it is. There are several alternatives, however: common genes (de la Fuente et al., 2020), neural efficiency (Genc et al., 2018), structural and functional brain networks (Martínez & Colom, 2021), elementary cognitive processes (Jensen, 2006), multiple cognitive processes (Demetriou et al., 2017), a phantom created by constrained executive function filter (Kovacs & Conway, 2016).

We still lack sound answers regarding the most likely formal interpretation of the positive manifold, but because the latter is a fact we can conceptually speak about the nature of intelligence. At this conceptual level, the intellect could be seen as an integrative general cognitive ability. It is not the ability to perceive environmental signals, to attend to the relevant information for achieving a given goal, to short-term retention, to long-term consolidation, or even to reason in the abstract realm. Intelligence can be conceptually considered as the glue that binds all human mental abilities. There are wide individual differences in how this integration is achieved. All humans can perceive, attend, memorize, and reason, but the key to answer the question of what intelligence is and what it is not, from a conceptual perspective, might lie in how all these mental abilities are integrated for making sense and shaping the environment (Colom, 2020; Haier & Colom, 2021). Conceptual definitions might not be crucial for doing scientific research, but they can be useful for designing fruitful playgrounds and joining forces for moving forward (Flynn, 2012). Quoting Linda Gottfredson (2016) “the brain (and the person) responds as a unit, whether answering items on a test or calculating the tip for a meal in real life.”

There is abundant research aimed at understanding the intelligence construct from an information processing perspective (Haier & Colom, 2021). Thus, for instance, evidence supports the leading role of cognitive constructs such as processing speed and working memory capacity, supporting the relevance of relational cognitive processing (Chuderski, 2019). Resistance to distraction (controlled attention) or the number of working memory slots were found to be much less relevant for intelligence. In contrast, the ability to construct temporary bindings was seen as crucial for intelligence: “constructing even single bindings seems to pose a difficulty for a substantial part of the population. Instead of the quantity of bindings that can be kept up, high intelligence might rely on bindings that are reliable and stable” (Chuderski, 2019). On-line reliable encoding of bindings was seen as core for intelligence. This framework might help to merge mainstream intelligence research, based on the positive manifold (individual differences approach) and the scientific study of intelligence from an information processing perspective (task approach). But factor analysts study what they call the structure of intelligence. Whether this means the proposed common cause exists is left for debate (e.g. Carroll, 1993; Borsboom et al., 2003).

Theorizing about the philosophical underpinnings of intelligence and its true nature should, of course, continue, but will likely do so at the same slower pace as it always has.

We turn now to measurement matters.

4. The measurement of intelligence

Scores obtained from standardized tests of intelligence do well when predicting a wide variety of real-life outcomes (Deary, 2020; Haier & Colom, 2021; Jensen, 1998; Strenze, 2015). Furthermore, there is evidence showing that *g* absorbs the achieved values of predictive validity (Lubinski, 2004). As noted by Zaboski et al. (2018) regarding academic achievement, “psychometric *g* explains more variance in academic outcomes than all broad abilities combined. Most broad abilities explain less than 10% of the variance in achievement and none explained more than 20%”. This is a recent example of the conclusion achieved by A. R. Jensen in 1998 after reviewing a century of research supporting the integrative nature of the intelligence construct defined as *g* and regardless of the most likely formal interpretation, as discussed above: “the *g* factor shows a more far-reaching and universal practical validity than any other psychological construct yet discovered (…) the removal of *g* from any psychometric battery, leaving only group factors and specificity, absolutely destroys their practical validity.”

Traditional measures of intelligence are still useful in applied settings, but tech developments now allow thinking in further ways to achieve the same goal. On the closing chapter of the Sternberg and Kaufman's *Cambridge Handbook of Intelligence* (Where are we? Where are we going? Reflections on the current and future state of research on intelligence) E. B. Hunt (2011b) invited intelligence researchers to pursue this goal: "The biggest challenge will be to expand research on intelligence from observations within the conventional testing paradigm to observations of behavior in everyday life." This is now doable and, therefore, standardized measurements can move towards a more ecologically valid assessment without losing the required accuracy.

The goal can be pursued using social networks (Kosinski, Matz, Gosling, Popov, & Stillwell, 2015; Kosinski, Wang, Lakkaraju, & Leskovec, 2016) and properly designed videogames (Malanchini et al., 2020; Quiroga & Colom, 2020). Also, the field can move from norm-referenced to criterion-related measurement. The cognitive system design approach helps to refine standardized measurements relying on already available information processing models: "Cognitive IRT (item response theory) models are mathematical models of cognitive processes and IRT models of response patterns. These models contain parameters to represent the cognitive demands of items, as well as the person's ability (…) the (intelligence) test of the future might be a set of generating principles, with previously known relationships to people's performance, which requires a fully developed cognitive model" (Abad, Quiroga, & Colom, 2017).

In this regard, the cognitive complexity continuum seems especially relevant because predictive validity of standardized measures of intelligence increases with the level of mental complexity in the predicted outcome regardless of their superficial appearance (Arend et al., 2003; Gottfredson, 2016; Hunt & Madhyastha, 2012; Jensen, 1998). Lubinski (2004) wrote in this regard: "everyday functioning in modern society has become more complex (…) the dimensions of educational, occupational, and social niches are becoming more abstract and fluid (…) the specific content is not fundamental, because the specific content of life is ever changing." Designing novel standardized measures of the general ability to deal with complexity is worthwhile, because of the requirement to integrate apparently disparate sources of information.

In short, we predict the emergence of novel measurements adhering Hunt's (2011b) recommendation, along with a proliferation of new ways of modelling the predictive validity of the cognitive manifold to real-world outcomes. This will likely be taken as further evidence that *intelligence* need not be modeled as a hierarchical model (following from the proliferation of non-hierarchical models).

5. Engineering the intelligence of humans

5.1. Historical raising of intelligence

Richard Haier acknowledged in 'The neuroscience of intelligence' Haier (2017) that "the ultimate purpose of all intelligence research is to enhance intelligence." It is easy to endorse this view because, as underscored by Douglas Detterman (2016) "human intelligence is our major adaptive function and only by optimizing it will we be able to save ourselves and other living things from ultimate destruction."

Indeed, raising intelligence has been a central focus of research since the beginning. In its time, trends come and go towards how to best raise intelligence. In the earliest years of raising intelligence, the focus was on the effects of preschool on intelligence (e.g. Ametjian, 1965; Di Lorenzo, Salter, & Brady, 1969; Karnes, Zehrbach, & Teske, 1974; Klaus & Gray, 1968; Weikart, 1966). In the 70s–80s, the focus seemed to be on large-scale early interventions to raise intelligence (e.g. Edwards & Stern, 1970; Ramey, Yeates, & Short, 1984). In the 90s–2000s the focus moved to leveraging stereotype and mindsets (e.g. Steele & Aronson, 1995; Aronson, Fried, & Good, 2002, Dweck, 2008). In the early 2010s, cognitive training became the rage (following Jaeggi, Buschkuehl, Jonides, & Perrig, 2008), with just a decade later skepticism seeming to have won the battle (Moreau et al., 2018).

This is not to suggest other attempts have not been active. Nutrition research has been present for decades in attempting to increase intelligence (see Protzko, 2018, for a meta-analytic review). Cognitive training was shown years before Jaeggi to raise local abilities in older adults, yet did not start a whole movement, possibly because of an initial lack of showing transfer across abilities (Ball et al., 2002; see also Protzko & Bailey, *Under Review*).

This is where prediction can go terribly awry. The fields of increasing intelligence are deeply driven by the publication of single, highly publicized, findings that direct the bulk of attention for a decade or two. This is not to suggest the above findings are not worthwhile, but the amount of focus they garner is disproportionate to other attempts to raise intelligence. Furthermore, there is little way to predict *which* future interventions will capture our attention. But we will try: An intervention will lead to the disproportionate capture of attention of a research field when its implementation shows: transfer from one focus to intelligence and when the intervention is relatively easy to implement from a personnel and regulatory standpoints (equipment to run is inexpensive, drug or medicine trials are absent, data is abundant, can be run in a laboratory). This setup allows the hope for inexpensive ways to raise intelligence. Something short, inexpensive, and effective.

5.2. Future raising of intelligence

Increasing intelligence test scores is quite feasible but moving up the core of the intellect is another issue (Estrada et al., 2015, see also Protzko, 2016, Protzko, 2015). It is tempting to explain the fadeout effect appealing to this distinction. Intervention programs can certainly move upwards the specific abilities and skills tapped by standardized measurements of the intelligence construct but modifying the integrative nature of the intellect is another battle (Dolan et al., 2006).

Haier and Colom (2021) discussed how intelligence could be enhanced beyond observed increases in tests' scores. Based on the available evidence, they accepted the fact that psychological interventions can improve specific mental abilities, but they were skeptical regarding its feasibility to increase the general ability devoted to the integration of the full set of mental abilities. Protzko (2018) did provide an example of why they reasoned in such a way: "a top-down causal structure (of intelligence) makes upward causation from subfactors (like working memory) to general intelligence impossible (...) much as we cannot move the hand on the barometer in the hopes it will change the weather, the structure of intelligence may make it impermeable to changing subfactors in the hopes of upward effects."

If the hierarchical causal structure is indeed the case, science must find ways for targeting the integrative general mental ability for uncovering the mechanisms that may change the weather. These might be identified at the genomic and at the brain levels. Recently developed technologies, such as CRISPR, are promising. James J. Lee speculated that "CRISPR could in principle be used to boost the expected intelligence of an embryo by a considerable amount." (Kozubek, 2016). We may have reservations, however, about this prophecy, because of the highly polygenic nature of intelligence (Deary, Cox, & Hill, 2021). Nevertheless, CRISPR is already successfully applied in biotherapy (Chen et al., 2020) and, therefore, will be important for many issues, intelligence among them. But with a trait as highly polygenic as general intelligence, isolating genes for editing may prove overly difficult.

Relatedly, we will see how tech advances are adapted for stimulating brain structure and function. We already know that drug and medication abuse can modify brain structural features for the worse (van den Heuvel et al., 2019) and this fact opens the door for finding substances that may enhance the core of the intelligence construct by hacking the brain. We think this would work much better if personalized. In this regard, Santarecchi and Rossi (2016) reported that response to brain stimulation using tACS is related with baseline intelligence differences: Individuals with higher intelligence levels are shielded against perturbation, whereas those with lower intelligence levels obtain measurable benefits from the intervention. Neuroscience findings regarding behavioral and brain data, as summarized by Colom and Román (2018), point towards that same direction.

There are certainly ethical issues surrounding raising intelligence that are fascinating to consider, but the history of scientifically attempting to raise intelligence has been continuing since at least the mid-20th century without any resolution on those issues. A full discussion is beyond the scope of our section here but attempts to raise intelligence will likewise continue without waiting for an ethical resolution.

In short, a crucial test for showing if scientific models about the positive manifold are correct involves demonstrating that we can engineer the intelligence of humans. Genomic, neuroscientific, and environmental models would be discarded if we cannot use the knowledge they provide for achieving the goal of intelligence enhancement. Period.

6. Intelligence and other psychological traits

We close this article acknowledging a fact that should be obvious (but we are afraid it is not): we must abandon the hope of truly understanding human intelligence in isolation. This trait interacts with other psychological traits such as those comprised by the personality construct.

Introducing a special issue addressing 'the ability-personality integration', Colom et al. (2019) stated: "attempts to integrate intelligence and personality constructs have a very long tradition in psychological research, but we still lack the type of consensus we already have for the most likely structure of intelligence or the key components of human personality for a joint taxonomy."

Integrative attempts have failed to attract attention from the scientific community. We think this must change. There is abundant evidence showing this interaction between intelligence and personality, including mental disorders (Caspi & Moffitt, 2018). All the relevant variables preceding ostensible behavior are cooked in the same pot (the brain). Therefore, it is mandatory to improve our understanding of how these variables are organized within a psychological cosmos that undoubtedly obeys some laws.

Intelligence researchers must cooperate with other scientists to get a big picture. The research by Smith et al. (2015) can be seen as a paradigmatic example. These scientists analyzed the relationship between 461 individual functional connectomes and 280 (demographic, psychometric, and behavioral) measures. Multivariate analyses identified one single mode of covariation resembling "descriptions of a general factor of intelligence, *g*, but extending it to include key aspects of real-life function, including years of education, income, and life satisfaction." They concluded that coordinated interactions among brain systems might give rise to a general mode of (integrative) function. Searching for knowledge about how this occurs in different individuals may be the most formidable challenge for the next 30 years of intelligence research.

7. Famous last words: bold predictions

We cannot deride the misplaced predictions of others without having the courage to make them ourselves. With that in mind, we offer these three for the next three decades of intelligence research.

1. There will be a proliferation of alternate models of the psychometric structure of intelligence that do not rely on a hierarchical model.

While it is our personal preference that we as a field instead work to have models compete against one another, and will personally work towards such ends, the incentive structure in science is not adequately prepared for such adversarial collaborations. Instead, more personal traction will be found by individual researchers by proposing their own models. Now that there is blood in the water about hierarchical models and a proliferation of tools allowing more researchers to use analyses like network analysis, more models to explain the positive manifold will likely emerge.

We predict, nevertheless, hierarchical models *in some form* will prevail and win the war (even when they can apparently lose some battles). What we already know about the intelligence construct (Caemmerer et al., 2020), how it responds to varied interventions (Protzko, 2018), and how the brain works (Protzko & Colom, 2021), favors this prediction.

2. In the next decade or two, a new study will be published that will derail researchers for a time, pumping abundant human and economic resources into the investigation of the phenomena.

This cyclically happens in any research field and will occur again. It is even possible the rate of these cycles will accelerate due to the exponential increasing (insane) rate in the number of publications.

We specifically predict the new wave will come from neuroscience. The study by Ozdemir et al. (2020) is a perfect example. Individualized brain stimulation will contribute to identify biomarkers of key components of the intelligence construct and, ultimately, to its integrative role.

3. Intelligence standardized tests, as we know them, will largely disappear from earth.

Tech progress will allow getting refined estimates of the general mental ability devoted to the integration, with higher or lower visible success, of the full set of specific mental abilities we use for language comprehension and production, attending to relevant cues while ignoring distractors, memorizing in the short-term contents relevant for the next move, recovering useful knowledge now from our database stored in long-term memory, abstract reasoning, and so forth.

The new estimates will be obtained merging genomic data, structural and functional brain features, and everyday life performance in social media where we expose our minds for free. Not just one of these, but all of them doing the job in some orchestrated way. At the end of the day, all actions preceding intelligent overt behavior take place in our brains. And at least in this era, humans just have one single brain.

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