Genetics and Education

Michael Thomas

The Inaugural Annual Learnus Lecture
2015
Genetics and education

The future is mechanism
Labelling
Screening
Personalised learning
What is changeable?
What do we want from education?
What’s surprising
The science
What use is that to teachers?
The interest
Genetics and education

The science

The future is mechanism

Labelling

Screening

Personalised learning

What is changeable?

What’s surprising

What do we want from education?

What use is that to teachers?
Many people think that some students can work to high levels and some cannot because of the brains they are born with, but this idea has been resoundingly disproved. Study after study has shown the incredible capacity of brains to grow and change within a remarkably short period of time.
Why are children so different in how well they do at school? ... We have assumed in education that this is all environmental.

The bottom line is, genetics is incredibly important, it’s so much more important than anyone ever thought... The differences between children are substantially due to DNA differences.

You know, Michael Gove’s Phonics Screening Check for 6-year-olds is one of the most heritable tests around. About 70% heritable.
Most differences are not due to the environment

So blaming teachers, parents, schools for all differences between children is unwarranted

Professor Robert Plomin
King’s College London
B.3 Distribution of student performance on the mathematics scale

PISA results for Mathematics (2006)

Countries are ranked in descending order of mean score. 12 countries with scores below 430 omitted.

- Gradation bars extend from the 5th to the 95th percentiles
- Mean score on the mathematics scale
- 95% confidence interval around the mean score
The interest

What do we want from education?

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What is changeable?

What's surprising

What use is that to teachers?

What do we want from education?
• What is heritability and how do you measure it?
Heritability is not about individuals

Heritability is about differences between individuals in groups
• Heritability = % of variation in an ability that is explained by the genetic similarity between individuals

<table>
<thead>
<tr>
<th>Identical twins</th>
<th>Non-identical twins</th>
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</thead>
<tbody>
<tr>
<td><strong>Twin 1</strong></td>
<td><strong>Twin 2</strong></td>
</tr>
<tr>
<td>56</td>
<td>50</td>
</tr>
<tr>
<td>34</td>
<td>32</td>
</tr>
<tr>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>83</td>
<td>78</td>
</tr>
<tr>
<td>..</td>
<td>..</td>
</tr>
</tbody>
</table>

Correlation = 0.9  Correlation = 0.6

1 - 0.9 = 0.1

Difference => 0.9 - 0.6 = 0.3
That’s 50% of effect

Full effect => 0.3 x 2 = 0.6
School effects are ‘shared environment’ effects, making children in the same school more similar – how large are they?

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>Unique environment</td>
<td>19%</td>
</tr>
<tr>
<td>Shared environment</td>
<td>12%</td>
</tr>
<tr>
<td>Genetic (heritability)</td>
<td>69%</td>
</tr>
<tr>
<td>School characteristics</td>
<td>17%</td>
</tr>
<tr>
<td>Family socio-economic status (SES)</td>
<td>83%</td>
</tr>
</tbody>
</table>

Study of academic achievement in 1063 pairs of seven-year-old twins (Walker, Petrill & Plomin, 2005)
The high heritability of educational achievement reflects many genetically influenced traits, not just intelligence

Eva Krapohl\textsuperscript{a,1}, Kaili Rimfeld\textsuperscript{a,1}, Nicholas G. Shakeshaft\textsuperscript{a}, Maciej Trzaskowski\textsuperscript{a}, Andrew McMillan\textsuperscript{a}, Jean-Baptiste Pingault\textsuperscript{a,\textsuperscript{b}}, Kathryn Asbury\textsuperscript{c}, Nicole Harlaar\textsuperscript{d}, Yulia Kovas\textsuperscript{b,\textsuperscript{e,\textsuperscript{f}}}, Philip S. Dale\textsuperscript{g}, and Robert Plomin\textsuperscript{a,2}

Edited by Michael S. Gazzaniga, University of California, Santa Barbara, CA, and approved September 10, 2014 (received for review May 13, 2014)

High heritability of achievement may also be due to many traits, such as personality, motivation, and psychopathology

Fig. 1. Model fitting results for additive genetic (A), shared environment (C), and nonshared environment (E) components of variance for GCSE and nine predictors.
Pleiotropy across academic subjects at the end of compulsory education

Kaili Rimfeld, Yulia Kovas, Philip S. Dale & Robert Plomin

Figure 1. Univariate model-fitting results. A = additive genetic, C = shared environmental, E = non-shared environmental components of variance for GCSE exam grades and intelligence.

Different academic subjects have similar high heritability. It appears to be largely a similar set of genes. And these are not just genes for general intelligence.
Pleiotropy across academic subjects at the end of compulsory education

Kaili Rimfield, Yulia Kovas, Philip S. Dale & Robert Plomin

Figure 2. Univariate model-fitting results with GCSE exam grades corrected for intelligence. A = additive genetic, C = shared environmental, E = non-shared environmental components of variance.

Different academic subjects have similar high heritability. It appears to be largely a similar set of genes. And these are not just genes for general intelligence.
Heritability versus DNA

• Heritability is about traits that run in families
• It is a separate question what the *actual genes are*, in terms of DNA variation

• The exact genes for educational abilities have been hard to track down
GWAS of 126,559 Individuals Identifies Genetic Variants Associated with Educational Attainment

Educational attainment = 40% heritable
Identified DNA variation explains around 2%
• What would genes influencing education look like if we could properly find them?

• What sort of things would they do?
**GWAS of 126,559 Individuals Identifies Genetic Variants Associated with Educational Attainment**

<table>
<thead>
<tr>
<th>Gene</th>
<th>Annotation</th>
<th>P-value</th>
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<tbody>
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<td>$1.4 \times 10^{-9}$</td>
<td>N</td>
</tr>
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<td>GBX2</td>
<td>neural tube development</td>
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<td>Y</td>
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<td>GBX2</td>
<td>regionalization</td>
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<td>Y</td>
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<td>neuron fate commitment</td>
<td>$2.6 \times 10^{-7}$</td>
<td>N</td>
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<td>GBX2</td>
<td>positive regulation of neuron differentiation</td>
<td>$4.6 \times 10^{-7}$</td>
<td>N</td>
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<td>GBX2</td>
<td>Notch signaling pathway</td>
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<td>RNF123</td>
<td>hemoglobin metabolic process</td>
<td>$8.2 \times 10^{-10}$</td>
<td>N</td>
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</tbody>
</table>

Terms directly related to neuronal or central nervous system function are marked with an asterisk *. 

**Brain**  
- Cognition  
- Motivation

But also:  
- Health  
- Immune system  
- Fitness  
- Metabolism  
- Digestion  
- Physical growth
When you’ve made the SES effects go away, the remaining differences are genetic
Family income, parental education and brain structure in children and adolescents

Kimberly G Noble¹,²,³, Jennifer M Houston³,⁴,⁵, Natalie H Brito⁶, Hauke Bartsch⁷, Eric Kan⁸,⁹, Joshua M Kuperman⁸,⁹,¹⁰, Natacha Akshoomoff¹⁰,¹¹,¹², David G Amara¹⁰,¹³, Cinnamon S Bloss¹⁰,¹⁴, Ondrej Libiger¹⁵, Nicholas J Schork¹⁶, Sarah S Murray¹⁰,¹⁷, B J Casey¹⁰,¹⁸, Linda Chang¹⁰,¹⁹, Thomas M Ernst¹⁰,¹⁹, Jean A Frazier¹⁰,²⁰, Jeffrey R Gruen¹⁰,²¹–²³, David N Kennedy¹⁰,¹², Peter Van Zijl¹⁰,²⁴,²⁵, Stewart Mostofsky¹⁰,²⁵, Walter E Kaufmann¹⁰,²⁶,²⁷, Tal Kenet¹⁰,²⁷,²⁸, Anders M Dale⁸,¹⁰,²⁹–³¹, Terry L Jernigan¹⁰,¹¹,¹²,²⁹ & Elizabeth R Sowell⁴,⁵,¹⁰

Socioeconomic disparities are associated with differences in cognitive development. The extent to which this translates to disparities in brain structure is unclear. We investigated relationships between socioeconomic factors and brain morphometry, independently of genetic ancestry, among a cohort of 1,099 typically developing individuals between 3 and 20 years of age.

1-2% of variability

N=1099
Socioeconomic status and executive function: developmental trajectories and mediation

Daniel A. Hackman,1 Robert Gallo,2 Gary W. Evans3

1. Center for Cognitive Neuroscience, Center for Neuroscience and Society, Department of Psychology, University of Pennsylvania, USA
2. Department of Mathematics and Applied Statistics, West Chester University, USA
3. Departments of Design and Environmental Analysis and Human Development, Bronfenbrenner Center for Translational Research, Cornell University, USA

Table 3 Intercorrelation among potential mediators and measures of socioeconomic status

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>.03</td>
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<td>Negative life events</td>
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<td>.07*</td>
<td>.18***</td>
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<td>Parent stress</td>
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<td>.07*</td>
<td>.50***</td>
<td>.10**</td>
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<td></td>
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<tr>
<td>Enrichment: Infant / Toddler</td>
<td>.10**</td>
<td>.01</td>
<td>-.23***</td>
<td>.02</td>
<td>-.10**</td>
<td></td>
<td></td>
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<td>Enrichment: Early Childhood</td>
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<td>-.02</td>
<td>-.24***</td>
<td>-.01</td>
<td>-.11**</td>
<td>.57***</td>
<td></td>
</tr>
<tr>
<td>Maternal sensitivity: Infant / Toddler</td>
<td>.12***</td>
<td>-.02</td>
<td>-.24***</td>
<td>.01</td>
<td>-.12***</td>
<td>.48***</td>
<td>.46***</td>
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<td>Maternal sensitivity: Early childhood</td>
<td>.09**</td>
<td>-.05</td>
<td>-.21***</td>
<td>-.01</td>
<td>-.12***</td>
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<td>.44***</td>
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<td>Early income-to-needs</td>
<td>.03</td>
<td>-.08*</td>
<td>-.24***</td>
<td>-.05</td>
<td>-.09**</td>
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<td>Maternal education</td>
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<td>-.04</td>
<td>-.23***</td>
<td>-.03</td>
<td>-.06</td>
<td>.40***</td>
<td>.49***</td>
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* p < .05; ** p < .01; *** p < .001.

ICHICD Study of Early Childcare. N = 1009 children in US followed from birth to 8 years
Genetics and education

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Screening

Personalised learning

The interest

What’s surprising

The science

What is changeable?

What use is that to teachers?

What do we want from education?
But

- What if the genetics stuff, the high heritability of behaviour, wasn’t a surprise?
  - Accept that some kids are brighter than others

- What if we moved straight on to the next question – what are we (parents, teachers, therapists, policymakers) supposed to make of the genetic results?
You may think

- Leave the genetic bit, you can’t change that. Focus on the things you can change, the environmental bit

- You’d be wrong in two ways
  - The genetic influences aren’t inevitable
  - And the genetic effects can tell you how best to change the environment
Genetics and education

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- What's surprising
- What use is that to teachers?
- The science
- What's surprising
- What is changeable?
- The interest

What do we want from education?
Sarah
Reading: C
Maths: A*
Sarah’s parents are both mathematicians

Dominik
Reading: B
Maths: B

Amy
Reading: B
Maths: C

Jack
Reading: D
Maths: E
Jack’s parents are unemployed and the household is chaotic

Ffion
Reading: A*
Maths: A*
Ffion’s parents want to transfer her to a private school

Billy
Reading: F
Maths: B
Billy really struggles with reading
• “No child left behind”
• “Educate the best, forget the rest”
• “Too much too soon”
• “Every child should realise their potential”
• “The Finnish model” – minimum levels of literacy and numeracy in our society
Average

Normal Distribution
Finnish model – minimum levels of literacy and numeracy in society
No child left behind
Educate the best forget the rest
Panacea...?
Panacea...?
• The relationship between the population average and individual differences is a tricky thing
The heritability of height is 80-90% (perhaps 1000 genes)

Men’s average height 'up 11cm since 1870s'

By Caroline Parkinson
Health editor, BBC News website

A century of growth
British males: Average height at age 21

Height cm

![Graph showing average height over time](source: Prof Tim Harlin et al, Oxford Economic Papers)
Relative vs absolute levels
Relative vs absolute levels
Relative vs absolute levels

![Graph showing relative vs absolute levels with standard deviations labeled as abcdefghi]
Relative vs absolute levels
Relative vs absolute levels
Relative vs absolute levels
Yet intelligence is 60-70% heritable!
The Phonics test

- Because scores are highly heritable does not mean we can’t improve performance for everyone (‘shift the distribution’)

- National education policy is often about shifting the distribution
Genetics and education

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Genetic effects are not deterministic

- Environmental interventions can alter genetic effects
- Phenylketonuria (PKU)
- Treatment:
  - Newborn screening
  - Diet low in phenylalanine + protein supplements
Teacher Quality Moderates the Genetic Effects on Early Reading

J. Taylor,1* A. D. Roehrig,2 B. Soden Hensler,3 C. M. Connor,1,3 C. Schatschneider1,3

Children’s reading achievement is influenced by genetics as well as by family and school environments. The importance of teacher quality as a specific school environmental influence on reading achievement is unknown. We studied first- and second-grade students in Florida from schools representing diverse environments. Comparison of monozygotic and dizygotic twins, differentiating genetic similarities of 100% and 50%, provided an estimate of genetic variance in reading achievement. Teacher quality was measured by how much reading gain the non-twin classmates achieved. The magnitude of genetic variance associated with twins’ oral reading fluency increased as the quality of their teacher increased. In circumstances where the teachers are all excellent, the variability in student reading achievement may appear to be largely due to genetics. However, poor teaching impedes the ability of children to reach their potential.

The ability to read proficiently is a critical skill, and children who fail in that skill are more likely to be retained a grade, drop out of school, and enter the juvenile criminal justice system (4)—all at substantial cost to society. Hence, we look to educators to ensure that children achieve proficient literacy skills; yet, a large proportion of the variability in children’s reading skills is associated with nonmeasurable factors like genes (2). Small differences in heritability (estimate of genetic influence) from twins that do versus do not share a teacher raise doubts about the effect of teachers on students’ reading development (3). At the same time, accumulating evidence from samples of unrelated children shows that teachers do affect children’s reading skill gains (4, 5).

The dilemma is that research examining unrelated children cannot address whether effects are associated with genes or with the shared

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*To whom correspondence should be addressed. E-mail: taylor@psy.fsu.edu
Use patients’ DNA to tailor treatment, doctors urged

Chris Smyth Health Editor

Patients should routinely have their whole genetic code read to decide on drug doses, one of the world’s leading experts on personalised medicine says.

Common medicines such as statins, painkillers and blood thinners can have radically different effects that could be predicted by analysing a patient’s DNA, said Gianrico Farrugia, chief executive of the Mayo Clinic in Florida.

Medicine is on the verge of a “seismic shift” where sequencing a patient’s whole genome becomes a routine starting point for treatment, Dr Farrugia said. Babies could have their DNA read at birth to help doctors treat them over the course of their lives, he suggested.

Doctors are increasingly excited about the potential of tailoring treatment to a patient’s genetic code rather than just their symptoms, with many of the latest cancer drugs targeting key mutations that drive the disease.

Trials are under way into deciding treatment based on the DNA profile of patients and their tumour, rather than where in the body it occurs, but genetic analysis is yet to become routine.

In an interview on a visit to Britain this week, Dr Farrugia urged doctors to “stop treating personalised medicine as special”. He added: “That’s a profound shift that needs to happen in this country if we really want to democratise individual medicine. Otherwise it will remain the domain of the few.”

Mayo patients are now routinely offered genetic analysis as emerging research finds it can help administration even of basic drugs, a process known as pharmacogenomics.

“There are some patients who tell you they take pain medication and it doesn’t work, and some say half a dose knocks them out,” Dr Farrugia said.

He said that the difference was down to genetic variations. About a quarter of patients had genes that mean they process drugs such as codeine very quickly, while others cannot break it down “so it’s like giving them candy”, he said.

With millions of patients urged to take cholesterol-lowering statins to cut their heart-attack risks, concern has centred on the side effects. Dr Farrugia said which individuals would get the most severe muscle pain was “totally predictable” using genetic analysis.

Currently gene sequencing costs more than $1,000, but Dr Farrugia said that prescribing based on genes was likely to cut costs by reducing side effects and the number of wasted doses.

“We want to get it down to $100. At $100 we think it becomes standard,” he said.
Deconstructed, parsed, and diagnosed.
A hypothetical example illustrates how precision medicine might deconstruct traditional symptom-based categories. Patients with a range of mood disorders are studied across several analytical platforms to parse current heterogeneous syndromes into homogeneous clusters.

Symptom-based categories
- Major depressive disorder
- Mild depression (dysthymia)
- Bipolar depression

Integrated data
- Genetic risk
- Polygenic risk score
- Brain activity
- Insula cortex
- Physiology
- Inflammatory markers
- Behavioral process
- Affective bias
- Life experience
- Social, cultural, and environmental factors

Data-driven categories
- Cluster 1
- Cluster 2
- Cluster 3
- Cluster 4

Prospective replication and stratified clinical trials

Insel & Cuthbert (2015) Science
• Your chairs have been fitted with DNA detectors
• See what we do. We change the environment.

• The question is which environment. And how.
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- Personalised learning

- The interest
- What’s surprising
- The science
- What use is that to teachers?
- What do we want from education?

What do we want from education?

What is changeable?

What is surprising

What use is that to teachers?
Personalised learning
I think a genetic view suggests an active model of education. In genetics, we call this a gene-environment correlation. It’s the idea that children create and modify and select environments that are correlated with their genetic propensities.

Professor Robert Plomin
King’s College London
Personalised learning?

- Learning Styles
  - Visual
  - Auditory
  - Kinesthetic

- Special Educational Needs
- Vary the "dosage"?

- Genetics to add "precision"?

- Cognitive acceleration
Adaptive learning

An educational method which uses computers as interactive teaching devices, to orchestrate the allocation of human and mediated resources according to the unique needs of each learner.
More subtle possibilities

• Different methods will work for different kids
  – e.g., interventions for behavioural difficulties
  – e.g., training working memory
Table 4. Correlations between change scores for externalizing behaviour, executive functions and CU traits.

<table>
<thead>
<tr>
<th>Change in Externalising Behaviour score</th>
<th>Total Sample N = 29</th>
<th>High CU N = 14</th>
<th>Low CU N = 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in CU trait score</td>
<td>.56**</td>
<td>.62*</td>
<td>.50</td>
</tr>
<tr>
<td>Change in Executive Function score</td>
<td>.55**</td>
<td>.44</td>
<td>.82**</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01.

Discussion

The results of this pilot programme evaluation offer initial support for the further development of the Let's Get Smart approach. Significant improvements across the first year of implementation were apparent on a number of measures of pupil behaviour and performance. Changes were mainly apparent in areas particularly targeted by the programme, for example in externalising behaviour, but not internalising behaviour. Changes were also found in measures of the cognitive and affective processes hypothesised to underlie children's externalising behaviour, and the magnitude of these changes was significantly associated with the magnitude of the improvements in externalising behaviour.

Staff perceptions of the changes made by pupils, collected through semi-structured interviews, supported many of the conclusions suggested by the results of the quantitative element of the study. Teachers reported that children were better able to understand and take control of their own behaviour, and that there were fewer instances of behaviour escalation that would previously have required physical restraint or another intervention from a member of staff. Despite a degree of scepticism at the outset, staff evaluation of the changes for themselves, as well as their pupils, was overwhelmingly positive. Furthermore, staff accounts of the changes to classroom and school practices provide evidence of the level of implementation of key programme components.

Programme components were selected to address the needs of children with different neurocognitive profiles. In particular, novel components were incorporated to address the needs of children with high CU scores. For children who had high CU scores at the start of the study, positive changes in CU scores over the course of the year were more strongly associated with behavioural improvements than were positive changes in executive function scores. The converse was the case for children with low CU scores, where positive changes in executive function scores were more strongly associated with behavioural improvement than positive changes in CU scores. These results suggest that this neuroscience-informed approach can lead to meaningful improvements in children's behaviour and performance.
Which environment to change?

- Won’t necessarily all be pedagogical or behavioural

- Could be health, diet, fitness, sleep, timing

- The potential drawback is that so many genes are involved (and so many environments)
Genetics and education

- The future is mechanism
- Labelling
- Personalised learning
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Does genetics point inevitably to screening?

- Early (pre-school)
- Independent of SES
- Better than ‘averaging the parents’?
The interest

What’s surprising

The science

What use is that to teachers?

What do we want from education?

What is changeable?

Personalised learning

Screening

The future is mechanism

Labelling

Genetics and education
• Would genetic screening be just another form of labelling?

• How do we translate (ethically, practically) from population risk to the individual?
The future is mechanism

Genetics and education

- Labelling
- Screening
- Personalised learning
- What is changeable?
- What's surprising
- What's the science
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- What use is that to teachers?
Educational neuroscience

• Genetics can’t just be about correlations, we have to understand biological and cognitive mechanisms

• Mechanisms that influence
  – learning,
  – willingness to learn
  – fitness to learn
  – opportunity to learn
  – persistence and retention of learning
Birth

Selective elimination

Synaptic combination

1

Language (phonic recognition, etc.)

Music (musical mind, etc.)

Natural learning (natural environment, etc.)

Sensation, attachment, sleep rhythm, etc.

Management

Judgment

Lexical knowledge

Experience- & need-driven learning

Present school system University

Rehabilitation, brain therapy, etc.

Age in years (log-scale) 10 100

Death

• What might genetic variation relevant to education influence?
  – Brain plasticity, brain power, neurotransmitter balance, development of low-level sensory and motor abilities, placing the right number of neurons in the right places and right wiring early in brain development
  – … but also maybe limbic system function (anxiety, approach-avoidance, exploit-explore in reward-based learning)
  – … maybe also immune response, oxygen transfer, energy consumption, resilience to stress

• We don’t yet know, but likely that answer will be wider than a focus on cognitive abilities alone
Genetics and education: Is there an example of a hereditary trait or feature that has an impact on education or teaching? Knowing that height is mainly inherited doesn’t seem to have an effect on the teaching techniques in high jump. So why are genetics of any interest to the average educator?
So why are genetics of any interest to the average educator?

Not all differences in educational achievement are environmental.

Society must determine the importance of overall population level vs. individual differences in education.

Genetic influences can reduce or increase in different environments: personalized learning.

Understanding of mechanism will tell us which environments to change: pedagogical but also health / fitness / timing?
Genes are not chains

• There are activities that humans haven’t yet thought of doing that, if we all did them tomorrow, differences between us would be heritable
The future is not fixed!
Thank you for your attention