WORKING GROUP 03

CHAPTER

3

Individual differences and influences on learning

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Abstract:

This chapter assesses the biological, psychological and social factors that contribute to individual differences in learning. Recent research suggests individual differences emerge from complex interactions between these factors. Here the focus is on reciprocities across the different levels and exploring the controversies and convergences across different disciplines. Cross-disciplinary research can lead to innovations in the science of learning. For example, culturally sensitive conceptualizations and assessments of psychological processes acknowledge the interactions between individuals' cognitive development with the sociopolitical factors that shape their environments. The findings caution against policy interventions that focus on a single assumed causal factor because educational outcomes cannot be predicted by one factor alone. Future research and policy should account for the interacting 'bio-psycho-social' (Youdell et al., 2020) factors that influence individual differences in education.

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3.1 Introduction

In recent years, significant attempts have been made to develop cross-disciplinary research alliances across the biological, psychological and social sciences. Broadly, as the biological and psychological sciences have moved towards a more social view of biological and psychological processes, the social sciences have also begun incorporating biological and psychological conceptualizations into their studies. The drivers of these fresh connections have included a number of scientific reconceptualizations of various aspects of human life, enabled in large part by technological and methodological advances such as genetic sequencing, psycho-physiological and biometric monitoring, and neuroscientific brain imaging. These include advances in molecular genomics and the recognition that genomic functioning is profoundly affected by social forces, environmental contexts and experiences. Social neuroscience has explored the ways in which brain structure and functioning are affected by social and environmental factors. Social psychology, too, has long examined how individual thoughts and cognitive processes are shaped by social, cultural and political contexts, interactions and influences.

The combination of genetics and social science to address education research questions and problems represents an emerging frontier of investigation and knowledge production.

Meanwhile the social sciences have begun exploring how biological and psychological factors interact with social phenomena. Such approaches include the involvement of sociologists in analyses of the interactions of socio-economic status with 'genomic reactivity'; engagement from social science with the ways in which social contexts and environments impact on bodies through processes of neural, cognitive and genomic plasticity; the emergence of interdisciplinary fields such as sociogenomics, environmental epigenetics, social epidemiology, and their role in understanding the social and biological factors involved in health, illness and socio-economic outcomes; and, more broadly, social scientific re-theorizing of the complex relations between 'nature' and 'nurture', 'biology' and 'culture', and 'bodies' and 'experiences' **(Meloni et al., 2018)**.

However, significant disciplinary differences persist across the biological, psychological and social sciences, especially in relation to questions over individual differences. These differences are especially evident in the field of education research, which by its nature encompasses diverse perspectives including sociology, philosophy, psychology and policy studies, as well as newer research endeavours such as educational neuroscience and the genetics of education. The central concept of learning is itself understood and approached differently by researchers from these disciplinary areas.

The purpose of this chapter is to explore emerging research that troubles hard internal/external divisions in how we conceive of individual differences in learning and educational outcomes, while acknowledging that there remain many unresolved tensions and conflicts in developing such multifaceted conceptions of individual difference and learning. The contributing authors discuss both the factors that are intrinsic to the person, which can influence learning, and how these interact with external factors

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CHAPTER

Over the two decades since the sequencing of the entire human genome, genetic sciences and their experimental techniques have opened up the human body to unprecedented levels of analysis at the molecular scale, and paved the way for new forms of diagnosis, prediction and treatment

in bidirectional, intersecting and transversal ways. Based on the collected perspectives in the chapter, we consider the prospects for future learning research and policy to take account of the intersecting and interacting 'bio-psycho-social' factors that shape individual differences **(Youdell et al., 2020)**, while taking very seriously the scientific, ethical and political implications of such biosocial conceptualizations **(Roberts and Rollins, 2020)**.

The following section focuses on the 'molecular' level of genes and their interaction with external environments, with contributions from behavioural genetics and social genomics. The key question addressed is: What are the genetic sources of individual differences and gene-by-environment interactions that contribute to individual differences, and what controversies and ethical tensions need to be negotiated regarding genetic explanations of learning for educational policy and/or practice? **Section 3.3** then focuses on psychological traits and states of individual difference, asking: How do individual differences in cognition, mindset, executive function and character influence learning, how have these psychological conceptions been deployed as policy solutions, and what tensions emerge when such psychological concepts are made policy-relevant? **Section 3.4** then focuses on the external social, cultural and environmental factors involved in individual difference, and draws on recent research seeking to identify productive inter-/transdisciplinary ways to account for biological, psychological, social and material interactions in the individual's learning experience. In the conclusion, we consider the implications of this research, addressing reciprocal interactions between molecular biological processes and functions, psychological dimensions of individual difference, and their intersections with social and environmental factors related to learning.

3.2 Molecular individual differences

Over the two decades since the sequencing of the entire human genome, genetic sciences and their experimental techniques have opened up the human body to unprecedented levels of analysis at the molecular scale, and paved the way for new forms of diagnosis, prediction and treatment **(Parry and Greenhough, 2018)**. While for some the data-intensive genomics revolution of the early twenty-first century promises great hope, such as the potential for 'precision medicine' tailored to the individual genome, for others it anticipates the return of hard biological perspectives on human lives and bodies, even perhaps new forms of eugenic discrimination based on individualized genomic screening and intervention **(Rose, 2007; Prainsack, 2017)**.

Within education, new research

> ...the emphasis is on bidirectional interactions between biological processes and social environments rather than internal ‘genetic architectures’ alone.

focuses on the molecular genomic underpinnings of individual difference, learning and educational outcomes, as detailed in the following sections. This genetics-based research related to education takes different forms, with varying degrees of sensitivity to environmental influence and interaction, and highly divergent ideas about its relevance for policy or practice **(Youdell and Lindlay, 2019; Williamson, 2020)**. Across these emerging studies, the emphasis is on bidirectional interactions between biological processes and social environments rather than internal ‘genetic architectures’ alone.

The combination of genetics and social science to address education research questions and problems represents an emerging frontier of investigation and knowledge production. The purpose of this section is to summarize the key findings, as well as the substantial gaps that remain in understanding the gene–environment interactions underpinning learning outcomes, and the very urgent ethical and political debates that such studies raise. We specifically address the genetics of learning, including recent results from twin studies and genome-wide polygenic scores (PGSs), as well as the possible policy implications, controversies and ethical tensions in this emerging field of molecular education research.

3.2 .1

THE GENETICS OF EDUCATION

Research in the genetics of education has a long history, stretching back to the eugenics movement and intelligence quotient (IQ) testing at the beginning of the twentieth century, encompassing biologically determinist accounts of racial differences in intelligence in the second half of the century, and extending to advances in molecular genomics in the twenty-first century **(Martschenko, Domingue and Trejo, 2019)**. Today, in the post-

...people learn differently, and one source of difference between them is their genes.

genomic era after the sequencing of the human genome, a new form of genetics-based research on learning and education is taking place. It is led by researchers in the fields of behavioural genetics, which combines psychological and genomic forms of analysis **(Harden, 2021)**, and social genomics, where genomics methods and insights converge with social scientific modes of analysis **(Mills and Tropf, 2020)**. This recent interest in the genetic and social factors involved in learning and education is characterized by ongoing conflicts between social and behavioural genomics researchers who see a new horizon for innovative research on education and learning in the human genome **(Cesarini and Visscher, 2017; Conley and Fletcher, 2017)**, and those who perceive it as a potentially dangerous return to eugenicist forms of biological determinism that have historically fixed differences and separated students along lines of 'natural' intelligence, race, ability, gender and so on **(Panofsky, 2015; Bliss, 2018)**.

According to research from the field of behavioural genetics, people learn differently, and one source of difference between them is their genes. The emphasis in such studies is on the heritability of outcomes. Here, heritability is defined as the proportion in the difference of life outcomes in a population that is due to genetic inheritance, rather than assuming simple intergenerational replication of behaviours or outcomes **(Tucker-Drob et al., 2016; Harden, 2021)**. Until recently, behavioural geneticists' major tool for estimating the impact of genetic differences between people was twin studies **(Polderman et al., 2015)**. Over a century of twin research has focused on learning, specifically measurable learning outcomes. Twin studies indicate that genetic influences on educational outcomes are partially mediated through genetic influences on cognitive abilities, but also through traits and characteristics that are often broadly referred to as 'non-cognitive skills', such as

...there is remarkable consistency in findings that both genetic and environmental influences matter.

intellectual curiosity, delay of gratification, motivation and persistence **(Rimfeld et al., 2018; Tucker-Drob et al., 2016)**.

Across all these learning outcomes, there is remarkable consistency in findings that both genetic and environmental influences matter. On average, twin studies report that genetic influences account for around 40 to 80 per cent of individual differences on a learning outcome, and environmental influences account for around 20 to 50 per cent of individual differences **(e.g. de Zeeuw, de Geus and Boomsma, 2015; Silventoinen et al., 2020)**. Regardless of the differences in overall magnitude of genetic and environmental influences for each learning outcome, twin studies report it likely that the same genes (in the twin modelling sense, as in the same general genetic influences on individual differences), and potentially the same environments, influence all these learning outcomes **(Plomin and Kovas, 2005)**. In addition, the same genes influence difficulty in a learning outcome as typical ability **(van Bergen, van der Leij and de Jong, 2014)**. Recent specialized twin models allow researchers to move beyond estimating the general genetic and environmental influences on a learning outcome, and instead to specify exactly what and how the environment influences learning outcomes, such as the effects of socio-economic status, household environment **(Hart et al., 2007)**, neighbourhood environment **(e.g. Little et al., 2019)**, and classroom and school environment **(Taylor et al., 2010)**. Other approaches use quasi-experimental methods to understand causal relations underlying a correlation between a learning outcome and an environmental influence **(van Bergen et al., 2018; Erbeli, van Bergen and Hart, 2019)**.

The most important conclusion from this body of twin research is that it is not simply a question of nature versus nurture but that learning occurs as a result of the

...significant controversy remains over whether twin studies overestimate heritability for social and behavioural traits.

interplay between nature and nurture functioning within an integrated framework. Knowing how this integrated framework operates is crucial for the development and improvement of effective learning support. However, significant controversy remains over whether twin studies overestimate heritability for social and behavioural traits **(Young, 2019)**; sufficiently account for other contextual specifics **(Tucker-Drob and Bates, 2016)** or the age of the twins in the twin sample **(Little, Haughbrook and Hart, 2017)**; and how specific skills are measured within each learning outcomes **(Hart et al., 2009, 2013)**. Thus, while behavioural genetics reports consistent evidence that a significant proportion of learning and educational outcomes is due to genetic heritability **(Rimfeld et al., 2018)**, some of the variability in outcomes is due to gene–environment interactions, for example, individual genetic makeup interacting with educational contexts **(Dick et al., 2015)**, further mediated by country-specific socio-economic factors **(Plaut et al., 2017)**.

3.2 .2

GENOME-WIDE POLYGENIC SCORES

Attempts to examine the interaction of an individual's genetic makeup with their environment began in earnest in the early 2000s. Over the last decade, a paradigm shift has occurred in the analysis of heritability, particularly as social scientists, economists and political scientists have begun adding genomic data to the other social variables they study **(Conley and Fletcher, 2017)**. Technological advances allowing researchers to measure the human genome directly have been employed by behavioural genetics researchers seeking to validate the core twin studies conclusion that people differ in their learning outcomes because of differences in their inherited DNA sequence

...polygenic score (PGS) indicates an individual's genetic propensity toward a specific outcome.

variation **(Plomin and von Stumm, 2018)**. Concurrently, new research teams and consortia have begun to develop 'social science genomics' approaches **(Mills and Tropf, 2020)**. Recent high-profile book publications introducing core ideas and policy implications of this work for education have led to significant mainstream media coverage, as well as scientific controversy and ethical debates **(Panofsky, 2015; Comfort, 2018; Henn et al., 2021)**.

Behavioural and social genomics research is enabled by the possibility of conducting genome-wide association studies (GWAS). GWAS is a research method that searches and compares DNA markers across the entire genome **(Pearson and Manolio, 2008)**, utilizing highly complex research set-ups that include vast databanks of genotyped data, laboratory hardware, bioinformatics software and statistical techniques **(Conley and Fletcher, 2017; Williamson, 2020)**. Such studies test associations with up to millions of measured genetic variants called single nucleotide polymorphisms (SNPs) **(Visscher et al., 2017)**. Using GWAS results, information about the SNPs in a person's genome can be aggregated into a single number, called a polygenic score (PGS), which indicates an individual's genetic propensity toward a specific outcome **(Belsky and Harden, 2019)**. Genome-wide PGS approaches recognize that all variations in human behavioural traits are influenced by hundreds or thousands of genetic variants, each with tiny effects **(Harden and Koellinger, 2020)**. However, they are limited to historical population samples of adults of European ancestry and therefore cannot be considered fully representative or generalizable to other population groups **(Herd, Mills and Dowd, 2021)**.

Research on the polygenicity of learning outcomes is now at the forefront of genetic research in education, with studies compiling huge samples of data from over a million people **(Harden, 2021)**. By studying SNPs, social and

Factors associated with completed education in European ancestry populations are correlated with schooling environment and developmental learning trajectories.

behavioural genomics scientists have identified specific regions of the genome that are associated with outcomes such as cognitive test performance and years of educational attainment **(Lee et al., 2018)**, with some research teams suggesting GWAS can reveal the genetic architecture of intelligence **(Malanchini et al., 2020)**. According to recent studies, among people with European genetic ancestry, PGSs are as strongly correlated with educational outcomes as other variables traditionally used in learning research – such as family income – showing that the influence of all genetic variations together captures up to 15 per cent of the overall variance in educational attainment **(Lee et al., 2018)**. Researchers report that roughly half of these polygenic effects are indirect, operating via the environment that parents generate and provide for their children **(Koellinger and Harden, 2018; Kong et al., 2018)**. These methods have been used to predict educational achievement on national standardized examinations **(von Stumm et al., 2020)**. GWAS have also been conducted on other education-related behaviours and outcomes including attention deficit hyperactivity disorder (ADHD) **(Demontis et al., 2017)**, obsessive compulsive disorder (OCD) **(Ritter et al., 2017)**, dyslexia **(Gialluisi et al., 2019)** and mathematical ability **(Chen et al., 2017)**.

Recent work also shows that individuals' genome-wide PGSs are correlated with their learning environments through a wide variety of direct and indirect mechanisms. Factors associated with completed education in European ancestry populations are correlated with schooling environment and developmental learning trajectories **(Lee et al., 2018; Belsky and Harden, 2019)**. Parents' genetic measures work through both transmission of genetic makeup and the creation of the environment to influence educational outcomes **(Belsky et al., 2018)**. Consistent with results from twin research, measured DNA

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variants are also associated with educational outcomes not just because they relate to cognitive abilities, but because they relate to individual differences in 'non-cognitive' skills **(Demange et al., 2021)**.

Irrespective of whether genetic effects are direct or indirect, it is important to realize that even the best currently available PGS is not useful for 'predicting' the educational outcomes of specific individuals. In addition, the portability of PGSs for educational attainment to different environments and different ancestry groups is very limited, and there remain limitations in understanding the causal processes that drive the observed associations **(Duncan et al., 2019; Lee et al., 2018; Martin et al., 2019; Rosenberg et al., 2019)**. Thus, within behavioural and social genomics, it is recognized that more discovery work with datasets on multiple populations, children and adolescents is needed, along with better methodologies and interventions to account for gene–environment correlation **(Fletcher and Conley, 2013; Harden, 2021)**.

Moreover, within the field of behavioural and social genomics calls have been issued to employ more sophisticated conceptualizations of 'environmental' influence, by drawing further on social science and sociological theory **(Mills and Tropf, 2020)**. From this perspective, one important critique of behavioural and social genomics is that it treats the 'environment' in 'atomistic' psychological terms such as influence of family, neighbourhood or school environment, whereas more sociologically informed analysis would highlight historical and social forces, social structures such as race, gender and class, and their complex influence on the genetic factors involved in learning processes and educational outcomes **(Herd, Mills and Dowd, 2021)**.

This means that GWAS data should not be used to make comparisons between groups, particularly groups defined by categories of ethnicity.

3.2 .3

CONTROVERSIES AND ETHICAL CHALLENGES OVER THE NEW GENETICS OF EDUCATION AND INTELLIGENCE

The re-convergence of molecular genetic research with education research is shaping what it means to learn, educate and progress through education. The increasing prominence of molecular genetic research in education brings both perils and promises that should be considered alongside each other. Importantly, and to reiterate, recent GWAS-based studies related to educational outcomes are primarily conducted using DNA samples from individuals of European genetic ancestry and focus on individual-level differences **(Popejoy and Fullerton, 2016)**. This means that GWAS data should not be used to make comparisons between groups, particularly groups defined by categories of ethnicity **(Herd, Mills and Dowd, 2021)**. Moreover, PGSs cannot 'predict' educational or other life outcomes for an individual accurately, and cannot cleanly separate genetic and environmental influences on those outcomes either **(Harden and Koellinger, 2020)**.

Despite the limitations of GWAS, calls for the incorporation of genetic data into education policy and practice have proliferated over the last decade **(Asbury and Plomin, 2013; Thomas et al., 2015; Kovas et al., 2016; Malanchini et al., 2020)**. Some researchers argue that genomic data can be used in social science research to better understand patterns of human behaviour and to evaluate and design more effective public policies, including education policies. Some have suggested that PGSs, in tandem with existing screening and progress monitoring technologies

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used by schools, could be used as an additional 'screening' tool to identify 'learning disabilities' and differentiate instruction for students **(Shero et al., 2021)**, although the feasibility of doing so remains questionable given the current partiality of available data and the very real ethical problems associated with differentiating students by biological measures of ability **(Roberts and Rollins, 2020)**.

More controversially still, other researchers believe genetic data might intersect with education policy through an approach termed 'precision' education **(Asbury and Plomin, 2013; Sokolowski and Ansari, 2018)**. Precision education, like precision medicine **(Ashley, 2015; Porche, 2015)**, focuses on the individual and the idea of devising specially tailored interventions based on individual-level genotyped data. Proponents of this model argue that policy-makers, schools, students and families would benefit from the ability to learn from a child's genetic data and create individualized education plans and interventions that maximize students' strengths and minimize their weaknesses **(Asbury and Plomin, 2013)**. At the heart of precision education is the belief that integrating genetics into education research could optimize educational processes **(Kovas et al., 2016)** or help to identify learning disabilities **(Hart, 2016)**.

Despite debate over the methodological feasibility of precision education **(Shero et al., 2021)**, some researchers have put forth policy proposals for the creation of 'genetically sensitive' school systems **(Asbury and Plomin, 2013)** and the subject is entering the Western public domain **(Briley and Tucker-Drob, 2019)**. The very idea of personalized, precision education is, however, highly contested even within the fields of behavioural and social genomics **(Harden, 2021; Herd et al 2021)**, and is the subject of criticism from ethical, scientific and social science perspectives **(Panofsky, 2015; Comfort, 2018; Williamson,** The very idea of personalized, precision education is, however, highly contested even within the fields of behavioural and social genomics.

2020). Behavioural and social genomics researchers themselves have raised concerns about over- or misinterpretation of their findings, highlighted the many persistent gaps in knowledge, and the potential deleterious consequences of moving too fast from basic research to practical or policy application in the field of education **(Conley and Fletcher, 2017)**.

The many possible applications of genome-wide association studies and PGSs in education and education research raise many other concerns over the misuse and misapplication of molecular genetic research in education **(Asbury, 2015; Sabatello, 2018; Martschenko, Trejo and Domingue, 2019)**. An ugly history of using eugenic ideologies to justify race and class-based differences and legitimize state-sanctioned violence **(e.g., Buck v. Bell 1927)** raises important ethical, social and policy questions about how to pursue equitable public education in the postgenomic era.

Such concerns include whether genetic research into socially valued behaviours like intelligence will intensify social inequalities **(Roberts, 2015)**, exacerbate bias and stigma **(Sabatello, 2018; Matthews et al., 2021)** or confine children to certain educational tracks that limit their agency.

In social environments built on systemic inequality and the continual disempowerment and marginalization of racialized groups, molecular genetic data could obscure ethical uncertainties, re-solidify sociocultural assumptions and resuscitate mythologies about inherent racial differences **(Roberts and Rollins, 2020)**. Moreover, a focus on genetics could detract from important social and environmental factors that impact student learning and achievement **(WG2-ch1)**. Any educational policy approach based on PGS values would run a substantial risk in perpetuating environmentally induced disadvantages of children or targetting the wrong cause for

The education research community should be proactive in avoiding past patterns of injustice and opening up interdisciplinary collaborations that keep equity in mind.

individual differences in schooling outcomes. Further, using PGSs to rank, sort and target children would involve a substantial risk in stigmatizing and demotivating those with low score values. Very little is currently known about how people react to information about their PGS values. One of the first studies that investigated how people react to learning their genetic risk for disease found that the effects of the perceived genetic risk were often self-fulfilling and sometimes greater than the effects associated with actual genetic risk **(Turnwald et al., 2019)**. Thus, informing children, parents and teachers about potential genetic influences on education may have unintended and undesirable effects. These possibilities raise questions about whether the risks of genetic research into socially valued behaviours and outcomes outweigh the potential benefits. The education research community should be proactive in avoiding past patterns of injustice and opening up interdisciplinary collaborations that keep equity in mind. Failure to do so would be a disservice to students, particularly those who are most underserved.

In sum, the development of molecular genomics in education research is controversial, owing to the history of biological discrimination stemming from the genetic sciences and the proliferation of biodeterminist myths of intelligence and outcomes. Such myths include the ideas that: (1) genetically influenced outcomes are 'innate' or 'hard-wired'; (2) social policy and environmental interventions will be ineffective for changing genetically influenced outcomes; (3) genetic influences explain racialized disparities in learning outcomes; and (4) genetic research validates existing social hierarchies. None of these myths survive scientific scrutiny. Consequently, scientists working in this area have a special responsibility to communicate their results responsibly and to combat commonly held myths about biodeterminism.

One's genetics do not determine one's educational outcomes, but according to much of the research reported above, they are associated with those outcomes in complex, bidirectional interactions with social and institutional environments.

3.2.4

SUMMARY

Molecular genomics has begun to identify specific associations between genetic variants and education-related behaviours and outcomes, and scientists claim modest causal genetic effects on learning. Many of the studies identified in this section are sensitive to the complex interactions of genes with environmental factors, and, in contrast to some well-publicized claims, do not report DNA to work as a 'blueprint' for success in education, intelligence or achievement. One's genetics do not determine one's educational outcomes, but according to much of the research reported above, they are associated with those outcomes in complex, bidirectional interactions with social and institutional environments. The findings provide scientific evidence challenging claims that generating PGSs for individual students could be used for 'personalized' or 'precision' education that is modified according to students' individual genetic differences and propensities.

Nonetheless, the science reported in this section remains 'in progress' and much more is yet to be understood about both the genetic mechanisms and environmental influences that shape educational and learning outcomes. Despite varied proposals to employ genetic data for educational practice or policy, no current scientific consensus exists on how such data might be used in educational institutions or by policy-makers. Too many political, ethical and scientific problems remain unresolved – and may not be resolvable in any meaningful sense – for social and behavioural genomics to be treated as a source of immediate policy-relevant knowledge and insight into the individual differences underpinning learning and educational outcomes.

3.3 Psychological individual differences

Children's educational outcomes depend on multiple, interacting cognitive systems that underpin learning across development. Broadly, some of the key cognitive processes that support a child's educational journey include language, memory and executive functions (EF), and higher-order processes such as critical thinking and reasoning. Learning is supported by this array of cognitive processes that must be coordinated and that explain individual differences in learning outcomes. In tandem with these cognitive processes, individual differences in psychological factors such as children's motivation and self-regulation support foundational academic skills such as literacy and numeracy. Literacy and numeracy skills, which are highly correlated

Children’s developing memory systems also support learning through their capacity to map new meanings and discover new patterns, which are associated with explicit and implicit learning, respectively.

throughout development, predict later academic success **(e.g. Ritchie and Bates, 2013)**. Literacy and numeracy are keys that unlock other learning opportunities and accompany children throughout their entire education journey, supporting their transition from primary to secondary and tertiary education.

Mastery of literacy and numeracy, key targets of primary schooling, are directly supported by core cognitive components that allow children to decode written language and master numerical concept **(e.g. Best, Miller and Naglieri, 2011; Fuhs et al., 2014; Earle et al., 2020; Jasi ska et al., 2021; Spiegel et al., 2021)**. Children’s language abilities, including phonological awareness (the awareness of the sounds that make up one’s language) and vocabulary, are the critical foundation for later literacy and numeracy skills **(e.g. Wagner and Torgesen, 1987; Goswami and Bryant, 1990; Korpipää et al., 2017; Cirino, Child and Macdonald, 2018)**. Children’s developing memory systems also support learning through their capacity to map new meanings and discover new patterns, which are associated with explicit and implicit learning, respectively **(Squire, 1992; Squire and Dede, 2015)**. Their EF further enable children to allocate their attention to relevant information in their environment, and maintain and manipulate that information in real time, while retaining the ability to incorporate new rules and new information; these abilities enable complex critical thinking, problem-solving and reasoning skills, and self-regulation, motivation and persistence. These abilities shape how children engage with teachers, peers and instructional content, indirectly contributing to their academic outcomes, as well as their social and emotional development. Recent research has accumulated a greater understanding of the sources of individual differences in children’s cognitive development, and some of the key findings are highlighted in the following sections.

Researchers in the developmental cognitive sciences have

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tracked children's individual developmental trajectories in relation to their learning outcomes, which has led to, among many things, a growing understanding of risk factors that increase the likelihood of children failing to realize their educational potential, as well as protective factors that increase the likelihood of positive educational outcomes. Research, including from the cognitive neurosciences, has found that early neurocognitive individual differences predict children's later academic attainment **(e.g. Supekar et al., 2013; Jasi ska et al., 2021).** These findings hint at the promise of highly individualized learning plans or intervention, where educational experiences may be customized based on individual psychological differences detected in early childhood using the latest developmental cognitive science tools, including neuroimaging methods. The ability to detect whether a child is at risk of experiencing difficulties in reading or mathematics before that child even starts school clearly has potential benefits; early detection has the potential to lead to early intervention at a time in a child's development when their brains are most plastic and therefore more receptive to intervention **(see WG3-ch6 on learning disabilities).** Yet, this potential application is not without controversy. There are no guarantees that a child who exhibits cognitive risk factors will suffer from deficits that impact learning later in development. Identifying children as at-risk also carries the risk of early categorization and stigmatization that may not be warranted by the potential benefits.

Individual differences in learning outcomes are strongly related to individual psychological differences, and much of the recent scholarship on individual differences in cognition and in learning has examined the extent to which individual differences are influenced by genetic and environmental factors, and gene x environment interactions; however, this field of research is only beginning to understand the complex relationships between

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genes, environment, and child development and learning. It is nonetheless clear that multiple aspects of cognition remain malleable to environmental influences throughout childhood. Practically, this means that cognitive development is both vulnerable to the negative effects of an impoverished and/or adverse environment, as well as responsive to intervention. Both 'sides of the plasticity coin' have direct relevance to education and social policy.

3.3 .1

INDIVIDUAL DIFFERENCES IN COGNITION AND LEARNING

Learning is a dynamic, iterative process that is simultaneously affected by individual and environmental factors, as well as the interaction between them. The core of these interactions is social in nature – learning is a social process. In a classroom context, these interactions are primarily with peers **(e.g. Vygotsky, 1978)** and teachers **(Hamre and Pianta, 2001)**. Learning itself changes the physical structure of the brain, and the changing structure in turn organizes and reorganizes how the brain functions **(Zatorre, Fields and Johansen-Berg, 2014)**. Two key sets of processes that are related to higher-order or deeper learning and complex skills such as critical thinking and reasoning are self-regulatory and motivational processes. Both are malleable to intervention, and both are linked to children's resiliency in high-risk environments **(e.g. McCoy, Gonzalez and Jones, 2019)**.

Self-regulation includes skills to regulate behaviour, emotions and thoughts in the pursuit of long-term goals, and the ability to delay gratification, pay attention and control impulsivity. Self-regulated learners apply these skills to the learning process and are guided by meta-cognition and reflection to achieve their goals. EF – a component of self-regulation –

are culturally universal skills that enable individuals to control their impulses, ignore distracting stimuli, hold relevant information in their mind, and shift between competing rules or attentional demands **(Obradovic and Willoughby, 2019)**. EF support classroom engagement and academic learning **(Jacob and Parkinson, 2015)**. Relatedly, 'grit' includes the persistence and passion that underlie goal-oriented behaviours towards a larger superordinate goal and has been linked to learning in several contexts **(e.g. Duckworth et al., 2011)**. Self-regulation and grit are strongly correlated but are not the same **(e.g. Oriol et al., 2017; Usher et al., 2019)**.

Motivation also plays an important role in learning throughout the lifespan and activates and sustains behaviour towards a goal. A key factor in motivation is an individual's mindset: beliefs about the nature of human attributes (e.g. intelligence) that affect one's actions **(Dweck, 1999)**. Growth mindset – the belief that intellectual abilities can be developed – can be taught and has been shown to improve academic outcomes in a nationally representative sample of adolescents in the United States (USA) **(Yeager et al., 2019)**. Motivations and mindsets are distinguished from general cognitive functioning and help explain achievement independent of intelligence test scores **(e.g. Murayama et al., 2013)**.

Both self-regulatory and motivational processes are malleable and should not be construed as fixed 'traits'. On the one hand, cumulative risk and the associated psychosocial stress **(Evans and English, 2002)** can affect the neural networks that underlie EF and self-regulation **(Blair, 2010)**. On the other hand, both can be improved in positive learning environments **(Renninger and Hidi, 2006; Diamond et al., 2007)**. For example, motivation develops throughout life and changes based on experiences with learning and other circumstances **(Turner and Patrick, 2008)**. Equitable learning

Growth mindset – the belief that intellectual abilities can be developed – can be taught and has been shown to improve academic outcomes...

> Individual variation in EF has been associated with learning-related outcomes such as school readiness, academic achievement and social competence in both high- and low-and-middle-income country settings.

outcomes for all groups of children cannot be achieved without assessing and addressing children's risk experiences. Targeting both environmental improvements and the development of self-regulation and motivational processes would greatly enhance children's learning opportunities.

Optimal learning rests on a wide range of inputs, such as adequate nutrition, exposure to language and a responsive caregiver. Exposure to risk in children's environments affects these inputs and is linked to poorer higher-order cognitive processes and learning outcomes. Risk factors can be in the form of a single event that severely disrupts a child's environment or they can be prolonged over an extended period of time. It has been argued that cumulative risk models – those that count risk factors in an additive manner – provide a more comprehensive representation of overall levels of adversity and capture how stress overwhelms children's adaptive systems **(Luthar, 1993; Evans, Li and Whipple, 2013)**. A cumulative risk index has been found to explain substantially more variance in children's development and learning than a single risk factor alone **(Sameroff et al., 1987, 1993)**.

3.3 .2

EXECUTIVE FUNCTIONS

EF are universally relevant cognitive skills – working memory, inhibitory control and cognitive flexibility – that collectively enable children to focus attention, regulate impulses, switch between competing demands and engage in goal-directed activities. Individual variation in EF has been associated with learning-related outcomes such as school readiness, academic achievement and social competence in both high- and low-and-middle-income country settings **(Zelazo et al., 2016; Obradovi and Willoughby, 2019)**. Developed across the life course, EF are shaped by contextual factors, including experiences of stress and adversity

...low-burden, flexible executive function strategies can be adapted to individual and place-based needs and embedded with children's daily academic routines.

resulting from systemic racial, social and economic inequalities **(Blair and Raver, 2012; Raver and Blair, 2020; WG2-ch5; WG3-ch5)**. It is paramount that we both reduce children's exposure to structural risks and foster opportunities to strengthen EF. The most effective interventions related to EF: (1) feature explicit cognitive training; (2) go beyond rote practice to continually challenge students' EF; (3) are implemented in a consistent, prolonged way; and (4) are adapted for use across diverse cultural contexts (Diamond and Ling, 2016). Instead of using standalone EF programs, which are often costly and challenging to scale, educators can integrate 'kernels of practice' – low-burden, flexible executive function strategies that can be adapted to individual and place-based needs and embedded with children's daily academic routines (Jones et al., 2017). To evaluate whether these approaches are working equitably, we must also design and utilize classroom-based executive function assessments that capture unique sociocultural experiences that foster EF, celebrate culturally relevant expressions and

The global education community would also benefit from the creation of more developmentally appropriate, culturally sensitive direct assessments of students' motivation-related behaviours...

applications of EF, and produce accessible, actionable data for educators **(Sarma and Mariam Thomas, 2020; Obradovi and Steyer, 2021)**.

Given that learning involves a combination of 'skill' and 'will', children's motivation to engage, invest effort, and seek out and persist through challenges influences their use of cognitive skills like EF as well as their classroom-based experiences and behaviours. Individual differences in motivation are related to key elements of learning, including focus, creativity, confidence and achievement **(Patrick, Turner and Strati, 2016)**. Rather than being conceptualized as a character trait, with students deemed 'more' or 'less' motivated, motivation is now recognized as situated and malleable across environments and instructional activities.

To ensure that all students are motivated to learn and not discouraged by mistakes, we should seek to remedy the inequitable contextual supports and discriminatory expectations that contribute to students' displays of low motivation and avoidance of failure **(Oyserman and Destin, 2010; Zusho, Daddino and Garcia, 2016)**. Indeed, programs and policies that promote (1) inclusive classroom climates and a sense of belonging, (2) supportive relationships with teachers and peers, (3) culturally responsive pedagogical approaches that affirm students' cultural identities and modes of learning, promote agency, and develop sociopolitical consciousness, and (4) positive racial and ethnic socialization have been linked to increased student motivation, particularly among historically marginalized populations **(Aronson and Laughter, 2016; Gregory and Korth, 2016; Wentzel and Muenks, 2016; Zusho, Daddino and Garcia, 2016; Gay, 2018; Kumar, Zusho and Bondie, 2018)**.

The global education community would also benefit from the creation of more developmentally appropriate, culturally sensitive direct assessments of students' motivation-related behaviours that do not rely on teachers' reports (which may be biased

As students embrace growth mindset beliefs, they take more advantage of learning opportunities and become more resilient in the face of academic set-backs and failure.

by other student characteristics) or self-reports (which are not feasible with young children). To ensure that assessments of EF and motivation illuminate inequities in educational settings rather than place a burden on individual children, researchers and educators must measure and analyze students' learning environments and opportunities in tandem with their skills and behaviours **(Obradovi and Steyer, 2021)**. One way in which some of these issues has been addressed is through school interventions based on concepts of student 'character', 'grit', 'resilience' and 'growth mindset'.

3.3 .3

GROWTH MINDSET

A growth mindset of intelligence is the belief that intellectual ability can be improved through dedicated effort and learning. By contrast, a fixed mindset of intelligence is the belief that intellectual ability is set and unchangeable. Adopting a growth mindset can lead students to interpret challenges and effort as opportunities for improvement rather than markers of low fixed ability **(Dweck and Yeager, 2019)**. As students embrace growth mindset beliefs, they take more advantage of learning opportunities and become more resilient in the face of academic set-backs and failure **(Blackwell, Trzesniewski and Dweck, 2007)**.

There has been considerable international interest in the use of growth mindset research to improve educational outcomes. One group of studies has measured the correlation between mindsets and outcomes, typically finding positive associations between endorsement of growth mindset and academic achievement. For example, studies of over 100,000 students in Chile **(Claro, Paunesku and Dweck, 2016)** and over 300,000 students in the USA **(Claro and Loeb, 2019)** found associations from r = .27 to .34 between growth mindset and achievement test scores in reading and mathematics.

More research is needed to understand where and why growth mindsets are most effective, and how cultural and contextual factors influence impacts...

Moreover, as part of the 2018 PISA assessment, the OECD surveyed over 500,000 students from 74 nations and found small positive correlations between growth mindset and achievement in 72 countries **(OECD, 2019)**. The two exceptions were China and Lebanon, which showed no association between mindset and achievement. Likewise, Li and Bates (2019) found no correlation between reported mindsets and grades in Chinese fifth- and sixth-grade students (N = 433), and Bahník and Vranka (2017) found no link between mindset and ability tests in university students from the Czech Republic (N = 5, 653), raising the possibility of cross-cultural differences in how mindsets shape academic performance.

There is also growing evidence that growth mindset interventions increase achievement for struggling students. A recent nationally representative study conducted with ninth-grade students in the USA demonstrated that brief, online growth mindset intervention increases grades for lower-achieving students **(Yeager et al., 2019)**, replicating effects from earlier research **(Paunesku et al., 2015)**. Experimental research from Peru **(World Bank, 2017)**, Norway **(Rege et al., 2021)** and South Africa **(Porter et al., 2020)** has also shown promising effects on outcomes like grades and enrolment in more advanced courses, though null effects were observed in a large British trial that implemented a teacher-delivered program **(Foliano et al., 2019)**. Notably, intervention effects are heterogeneous: growth mindset programs tend to improve the achievement of students who are most at risk of poorer outcomes, and those in classroom environments where newly acquired growth mindset beliefs can be put into practice **(Walton and Yeager, 2020)**.

More research is needed to understand where and why growth mindsets are most effective, and how cultural and contextual factors influence impacts, including, for instance, how teachers' knowledge and understanding of growth mindsets may be related to teachers' effectiveness in the classroom. Research also needs to acknowledge that practical interventions to elevate students' growth mindsets, and related characteristics, are also situated in broader social and political movements.

3.3 .4

CRITICAL DISCOURSE ON 'CHARACTER' AND RELATED CATEGORIES WITH A SOCIAL AND CULTURAL VIEW

Recent policy interest in 'character education', as well as in the related concepts of 'grit', 'growth mindset' and 'resilience' can be framed within what Allen and Bull **(2018)** describe as a 'turn to character' within contemporary capitalism. In this 'turn', individualized qualities such as grit, perseverance, resilience and 'bounce-backability' are framed as both the causes of and solutions to unequal life outcomes. As Allen and Bull **(2018)** describe, this focus on responsibilizing the individual has occurred in the context of increasing inequality within nation states and an intensification of neoliberalism globally whereby the onus shifts from the state to the individual for managing the consequences of inequality. In sum, character education teaches people that individuals must be 'moral' (in a narrow sense of the word) because the system – free market capitalism – cannot be.

Thus, character education is seen as making increased inequality morally acceptable. Pre-dating these more recent arguments, however is a longer history of critical discussion. It has been argued that character education serves a conservative political agenda as it focuses on perpetuating the status quo rather than opening up space for change **(Boyd, 2016)**. Further critiques include its reliance on a behaviourist ontology, and its assumption of a Christian ontology of the human in

It has been argued that character education serves a conservative political agenda as it focuses on perpetuating the status quo rather than opening up space for change.

...positive psychology legitimizes inequality by suggesting that if only people had more 'grit' they could be socially mobile – even in a context where social mobility is becoming more and more difficult.

which children are assumed to be inherently sinful and need to be taught self-control **(Kohn, 1997; Davis, 2003, p. 37; Winton, 2008; Jones, 2009, p. 39)**. Overall, character education works on the assumption that morality takes the form of supposedly universal conservative 'virtues' such as self-control, loyalty and obedience, ignoring a wider set of values that emphasize connection to others, political imagination and critical thinking **(see section 3.3; Kohn, 1997; Suissa, 2015)**.

In the United Kingdom (UK), the influence of character education on policy has been traced back to the political aspirations of the John Templeton Foundation. Also drawing on funding from the John Templeton Foundation is the 'positive psychology' movement which mobilizes a very similar set of concepts to character education, advocating for qualities such as 'grit' and 'resilience'. While 'character' approaches tend to foreground morality, positive psychology draws on an intellectual and educational lineage around 'non-cognitive' or 'soft skills'.

However, their similarities are greater than their differences. Both posit individual character as the cause of, as well as the solution to, a wide variety of social problems as diverse as poverty, poor educational outcomes or the gender pay gap **(e.g. Gill and Orgad, 2018)**. Both obscure – or at least downplay – any social causes of such issues such as, in the UK, policies of 'austerity' whereby state services such as legal aid or support for domestic abuse are cut. Both rely on responsibilizing the individual (or at most, the family) in addressing these social problems. For example, positive psychology legitimizes inequality by suggesting that if only people had more 'grit' they could be socially mobile – even in a context where social mobility is becoming more and more difficult. It is no surprise, therefore, that those who are most strongly exhorted to develop 'character' and 'resilience' are working-class children and young people, women, people of colour and other marginalized populations.

3.3 .5

SUMMARY: SITUATING COGNITION, MINDSET AND CHARACTER

Psychological research on individual differences in cognition, motivation, EF, growth mindset and related approaches has begun to develop novel conceptualizations of cognitive and intellectual malleability, as well as culturally sensitive approaches which acknowledge the dynamic bidirectional interactions of individuals and environments. The scientific evidence to date has clearly established that individual differences in cognition, to a large extent, underpin individual differences in learning. The research suggests exciting applications whereby early cognitive assessments carry predictive value for identifying children at risk of struggling in school and who may need additional support to realize their academic potential. The research hints at important targets of intervention – and by extension, education – and social policies that best support children's development and learning.

Recent research on psychological individual differences, such as character education, carries political connotations. Character education, 'grit' and growth mindset approaches favour an individualistic model of education prioritizing self-improvement as a route to social mobility, while obscuring the causal and environmental factors that produce social and educational inequalities. Such approaches are politically appealing as they assume outcomes can be improved through the identification of individual differences and interventions aimed at enhancing individual capacities, but limited because they neglect the dynamic interactions of individuals with their wider environment. Our aim should be to leverage the research on psychological individual differences to understand how individual children differ and to build societies that support all children to realize their full potential.

...early cognitive assessments carry predictive value for identifying children at risk of struggling in school and who may need additional support to realize their academic potential.

3.4 Social factors and individual differences

The previous sections have outlined research in the biological and psychological sciences that have sought, in various ways, to incorporate social factors into the analysis of individual differences related to learning and educational outcomes. In this section, we engage more specifically with the question of how social in some branches of recent social theory, the social environment is increasingly understood to get 'under the skin' to reshape biological and psychological processes, while, in a reciprocal manner, embodied actions of individuals also extend 'out of the skin' to reshape the environments they inhabit.

factors interact with biological and psychological factors. This is unfamiliar territory for social scientific approaches to education and learning, which are normally focused on external social structures and practices and their effects on students' behaviours and actions rather than on internally embodied factors.

Many social science approaches to understanding how individual differences impact on educational outcomes actively seek to disrupt individualized biological and psychological accounts of learning. Researchers contend instead that social class, gender, race and other cultural, economic and political factors remain the main determinants of educational opportunities and outcomes **(Apple, Ball and Gandin, 2010)**. Important recent work on 'intersectionality', informed by critical race theory, has begun exploring how these factors interact within and through educational institutions and policies, reproducing patterns of discrimination and exacerbating existing social, economic and cultural advantages and disadvantages **(Tefera, Powers and Fischman, 2018)**.

However, in some branches of recent social theory, the social environment is increasingly understood to get 'under the skin' to reshape biological and psychological processes, while, in a reciprocal manner, embodied actions of individuals also extend 'out of the skin' to reshape the environments they inhabit **(Meloni, Williams and Martin, 2016)**. These emerging understandings have led to studies exploring, for example, the impact of socio-economic gradients on brain plasticity and development, as well as other biological adaptations in response to exposure to stress, trauma and socio-economic adversity and disadvantage **(Meloni et al., 2018)**. Some of the key intersections of the biological, psychological and social sciences can be found in studies of social and behavioural epigenetics and social neuroscience **(Rose, 2007)**.

socio-economic factors profoundly shape individual differences in cognition and affect the academic trajectories of children around the world.

Social scientific analyses of these interacting social, biological and psychological dynamics in relation to education are relatively rare. In this section, we address the bio-psycho-social dynamics of learning and education, insisting that individual differences related to learning be considered as interdependent with intersecting social and environmental factors including socio-economic gradients, (dis)advantage, race/ ethnicity, gender and other sources of personal identity formation, along with the full range of social, physical and material aspects of environments in which learning takes place **(WG2-ch4)**. The first section explores the ways in which socio-economic factors may impact on individual neurocognitive development, then turns to how ideas about epigenetics – how social environments affect how genes work within human lifetimes and across generations – has been applied in education, before summarizing recent social scientific research on the 'biosocial' aspects of learning.

3.4 .1

SOCIO-ECONOMIC GRADIENTS AND INDIVIDUAL DIFFERENCE IN LEARNING AND BRAIN DEVELOPMENT

Nearly 12 million American children were living in poverty prior to the COVID-19 pandemic **(Children's Defense Fund, 2020)**, and more than a billion children were impacted by poverty around the world **(UNICEF, 2020)**. It is estimated that an additional 150 million children globally have fallen into poverty since the start of the pandemic **(UNICEF, 2020)**. Socio-economic disparities have for decades been linked with children's cognitive and socio-emotional development and academic achievement **(Johnson, Riis and Noble, 2016)**. These differences emerge in early childhood **(Noble et al., 2015a)**

and persist throughout the lifespan **(Moorman, Carr and Greenfield, 2018)**. Thus, socio-economic factors profoundly shape individual differences in cognition and affect the academic trajectories of children around the world.

Research has shown that the strongest links between family socio-economic background and children's neurocognitive performance tend to cluster in certain domains, including language, memory, EF and social-

> Differences in children's experience are likely at least partially responsible for these socio-economic disparities in neural and behavioural development.

emotional development **(Pace et al., 2017; Lawson, Hook and Farah, 2018; Merz, Wiltshire and Noble, 2019; WG3-ch5)**. More recently, a burgeoning field has centered on identifying socio-economic disparities in the developing brain **(Noble and Giebler, 2020)**. Indeed, research has linked socio-economic factors to certain structural and functional brain differences which underlie the aforementioned skills. For instance, socio-economic differences in cortical surface area, cortical thickness and grey matter volume have been commonly noted in frontal and temporal cortical regions **(Noble et al., 2015b; McDermott et al., 2019; Merz et al., 2020; Noble and Giebler, 2020)**, which support the development of language, EF and emotion regulation. Other work has linked family socio-economic characteristics to children's hippocampal volume, which is critical for learning and memory **(Hair et al., 2015; McDermott et al., 2019; Merz et al., 2019)**.

Differences in children's experience are likely at least partially responsible for these socio-economic disparities in neural and behavioural development. While more work is needed to fully understand the specific experiences that may account for these links, it is highly likely that parenting practices, social context and social supports for learning are mechanisms that account for these disparities. For example, cognitively and linguistically enriching experiences may serve as proximal factors that mediate neurodevelopmental differences **(Rosen et al., 2018; Merz, Wiltshire and Noble, 2019; Merz et al., 2019)**. Several recent studies have found that contingent, responsive verbal interactions between parents and children, or other forms of cognitive stimulation in the home, may mediate the links between socio-economic disparities and children's brain development **(Romeo et al., 2018a, 2018b; Rosen et al., 2018; Merz et al., 2019)**. Alternatively, exposure to chronic stress within the family has cascading effects on multiple brain and body systems, and has also been considered a likely mechanism linking socio-economic disadvantage to

Neuroplasticity describes how the brain is materially affected by learning, experience or environmental stimuli and interaction...

neurodevelopmental differences **(Dufford and Kim, 2017; Merz et al., 2019)**. Finally, although these differences in neurodevelopment are often portrayed in the literature as a 'deficit', with poverty treated as a 'scar on the brain', it is important to note that neuroplasticity theory suggests that these changes may reflect developmental adaptation to childhood adversity. Neuroplasticity describes how the brain is materially affected by learning, experience or environmental stimuli and interaction, as synaptic connections between neurons are 'wired' together, trimmed, pruned and 'rewired' across the entire lifespan **(Tovar-Moll and Lent, 2016)**. Indeed, some scholars note that children reared in poverty or other harsh environments may actually develop 'hidden talents' or enhanced skills that are optimized for high-adversity contexts **(Ellis et al., 2020)**.

The impact of socio-economic gradients on neurocognitive development and neuroplasticity highlights the importance of bringing social scientific understandings of the impact of social, economic, cultural and political factors to the study of individual differences, and in particular the complex biological and social dynamics involved in such processes. This is particularly important as recent developments in 'neurotechnologies' such as brain imaging may lead to novel conceptions of the impact of social forces on the plastic learning brain, and potentially controversial proposals for policy and practice interventions to 'improve' brain function **(Williamson, 2018)**. Such interventions, it has been proposed, might include learning software that adapts to measures of individuals' neurocognitive processes **(Royal Society, 2011)**, electrical brain stimulation to enhance cognitive performance **(Schuijer et al., 2017)** and other attempts to 'sculpt' an individual's unique learning brain **(Marope, 2016)**.

Research has begun exploring the possible epigenetic mechanisms that affect individual development, cognition, educational trajectories and long-term life outcomes.

3.4 .2

EPIGENETIC EDUCATION

Epigenetics is the process by which environments affect the molecular level of human bodies by regulating gene expression, and therefore affect phenotypical behaviours and traits without changing DNA itself. Research in epigenetics is interested in how social environments affect gene expression. Epigenetics proposes that the environment, including material and social factors, plays an important role in shaping how genes work within human lifetimes and across generations **(Pickersgill et al., 2013)**. Recently, epigenetics studies have been prominent in discussing how maternal nutrition or early-life trauma and stress affect offspring to increase the risk of disease or behavioural problems later in life. However, there is also the risk of perpetuating social discrimination based on the assumption that certain individuals might be 'epigenetically damaged' **(Müller et al., 2017)**. Such observations are significant for the social sciences as they open up questions about appropriate public policy responses to address unjust living conditions and other environmental factors that affect health and behaviour.

Research has begun exploring the possible epigenetic mechanisms that affect individual development, cognition, educational trajectories and long-term life outcomes **(Youdell, 2019)**. In terms of biological mechanisms, some ways in which epigenetics have been considered in relation to education include effects on learning and cognition, memory formation and storage **(Day and Sweatt, 2011a, 2011b)**. In particular, such studies have focused on the impact of genetic modification on the establishment of new active synaptic connections in the brain, which may be affected by social circumstances **(McEwen, 2015)**, as well as other learned behaviours **(Dias et al., 2015)**. Among the epigenetic mechanisms considered by such work are experiences such

...existing social systems and structures of schooling might themselves affect learning at the molecular genomic level, thus calling for the design of enriched environments for education...

as stress and physical exercise. Other studies have considered the epigenetic processes that might affect the development of cognitive abilities and learning within the educational environment itself, positing that existing social systems and structures of schooling might themselves affect learning at the molecular genomic level, thus calling for the design of enriched environments for education and therapy to develop healthy human brains and behaviours **(Frías-Lasserre, Villagra and Guerrero Bosagna, 2018).**

As these examples indicate, research on epigenetics in education suggests that social, economic, cultural and other structural aspects might physically impact on the development of individual differences that then affect learning and educational outcomes. However, this body of research remains emergent rather than conclusive, and many of the conclusions are drawn from animal studies and extrapolate to human learning and cognitive processes **(Pickersgill, 2020).** Sociological studies showing how ideas about epigenetics have been taken up in education have begun to emerge, and show how they are often based on promises of improving interventions, which are attractive to policy-makers, rather than strong empirical evidence **(Gulson and Webb, 2018).** Moreover, there is a tendency to overclaim the malleability and plasticity of the epigenetic body as a site of potential modification and improvement, grounded in highly normative ideals of an ideal learner and superficial accounts of environmental influence that oversimplify or gloss over social, cultural and political complexity **(Pickersgill, 2020).**

Despite these notes of critical caution, epigenetics remains a significant potential site for productive interdisciplinary investigation between the social sciences, psychological and cognitive science, and the genomic sciences in relation to education. Future research in this area will require highly specialized disciplinary expertise and careful discussion to identify epigenetic mechanisms, including complex social factors, that impact on the individual differences of learners and their learning outcomes

3.4 .3

MORE-THAN-HUMAN' APPROACHES TO INDIVIDUAL DIFFERENCE

In the past decade, a key development and application of more-than-human approaches to education has come through 'Common Worlds' perspectives.

More-than-human approaches to childhood have been a constant, although growing, part of childhood and education studies since 2000 **(Prout, 2005; Horton and Kraftl, 2006; Lee and Motzkau, 2011; Kraftl, 2020; Nxumalo and Villanueva, 2020)**. Whilst varied, these approaches share a conceptual, political and ecological commitment to examining how humans' lives are inextricably entwined with those of non-humans (e.g. animals, plants, earth systems or technologies). Scholars working in these areas have attempted to find new research methods and forms of writing that can offer insights into the workings of more-than-human 'entanglements' (mixtures of human and non-human). Those entanglements might be found in the constitution of school architectures through building technologies **(Kraftl, 2012)** or in the ways in which technologies such as mobile phones are used with/in 'natural' educational settings such as forests **(Smith and Dunkley, 2018; Land et al., 2019)**.

In the past decade, a key development and application of more-than-human approaches to education has come through 'Common Worlds' perspectives **(Taylor and Pacini-Ketchabaw, 2018)**. Common Worlds scholars have attempted to study, analyse and imagine educational spaces in which a commitment to the shared worlds of humans and non-humans is foregrounded, More-than-human approaches to learning, in sum, open up the category of 'individual differences' to respect and account for both the differences between all humans and non-humans and the relations between them.

and in which non-humans are considered actors that can bring about change in any given learning situation **(Blaise and Hamm, 2019; Haynes and Murris, 2019; Taylor, 2019; Weldemariam, 2019)**. The key finding from such studies, for example, is not that children learn from animals but rather that they learn with them – developing mutual understanding, learning how to live with other species and respond to them, and learning how to deal with death (e.g. on encountering a dead animal during a walk). Much – but not all – of this work has taken place in outdoor, early childhood settings, particularly in settler colonial contexts such as Canada and Australia. This has enabled scholar-pedagogues to support children in developing critical reflections on how (for instance) animal species introduced by settler-colonizers might be understood in complex and perhaps contradictory ways – both in terms of how humans might care for those animals, and in terms of how they articulate their experience with forms of colonial violence **(Taylor, 2019)**.

Whilst some 'biosocial' approaches to childhood and education may be critiqued for ignoring or downplaying human differences (such as ethnicity, geographical location, sexuality or gender), researchers of more-than-human childhoods and learning have sought to remain attuned to and respectful of differentiation in all its forms. This may mean a critique of what some view as stable identity categories (like gender), but also implies sensitivity to how (for instance) gender performances might be variously and locally manifested in and through relations with non-human others **(Blaise and Rooney, 2019)**. It also means a keen attentiveness to place: to how learning is a multispecies achievement, which is focused both on the histories of land and ecological futures that can embrace and treat responsibly all forms of difference – human and non-human **(Taylor and Pacini-Ketchabaw, 2018; WG2-ch8, WG3-ch5; WG3-ch7)**. This resonates clearly with both 'deep green' ecological thought **(e.g. Plumwood, 2002)** and efforts to create 'place-responsive

...the ‘environments’ that affect and shape individual differences consist of much more than categories such as family, neighbourhood, school or socio-economic status.

pedagogies’ within more critical forms of environmental education **(e.g. Mannion, Fenwick and Lynch, 2013; Spillman, 2017)**. Some of this work also resonates with indigenous land education and its attunement to decolonial and more-than-human place relations **(Tuck, Mckenzie and McCoy, 2014)**.

More-than-human approaches to learning, in sum, open up the category of ‘individual differences’ to respect and account for both the differences between all humans and non-humans and the relations between them. Together with social science approaches to biosocial learning, epigenetics and neuroplasticity described in the sections above, these emerging bodies of research complicate notions of individual difference and learning that emerge from primarily biological and psychological accounts. They also highlight how the ‘environments’ that affect and shape individual differences consist of much more than categories such as family, neighbourhood, school or socio-economic status. They draw important attention to the ways in which individual differences are profoundly shaped by complex social structures, economic and political factors, interactions with material environments and ecologies, and other living beings.

3.4 .4

SUMMARY: SOCIAL, BIOLOGICAL AND MATERIAL INTERSECTIONS OF LEARNING

Research on the molecular and psychological dimensions of individual difference and its influence on learning is increasingly attentive to the interactions of the individual with complex environments and social-structural factors such as socio-economic disparities and physical settings. As recent research

Individual differences that affect learning emerge from a wide range of molecular, psychological, social and environmental factors, and their interactions.

on neurocognitive plasticity and epigenetics in relation to education has shown, there is a pressing need for studies that can identify and examine the ways in which complex social factors may impact on human bodies and lives.

At the same time, social scientific analyses foreground the social and environmental complexities of the environments and social factors that shape individual differences, personal identities, and learning processes and outcomes. Sociological research emphasizes the irreducibility of individual differences to single categories, and instead highlights how social and economic factors, the experience of race, ethnicity, gender, social class, culture and family affect how individuals come to identify themselves, and the effects of these intersecting factors on learning and education. Biosocial approaches acknowledge the interactions of embodied biological processes, environmental factors and social forces. 'More-than-human' research also highlights the powerful role of 'non-human' beings, materials and physical settings on individual differentiation, and the implications of this recognition for the design of learning experiences and spaces.

Despite their diverse disciplinary perspectives, such studies demonstrate the need for multidimensional policy responses and practices in education, rather than interventions focused narrowly on raising outcomes by addressing single, specific influences on learning.

3.5 Key findings

Individual differences that affect learning emerge from a wide range of molecular, psychological, social and environmental factors, and their interactions. Diverse forms of research across the genomic, neural, cognitive, psychological and social sciences indicate that learning processes and educational outcomes are not reducible to either genes, brains and minds, nor to social and environmental forces. As this chapter demonstrates, individual differences may emerge from the bidirectional interactions of intrinsic (yet malleable) biological features, such as genomic expression and brain structure, and external environmental factors, including social and economic forces, cultural influences, and physical and material environments. We offer here a series of key insights and policy recommendations from the research covered in this chapter.

Molecular genomics both increasingly specifies the complex polygenic associations between DNA and educational outcomes, and identifies the profoundly powerful role of gene–environment interactions that shape individual differences and affect learning. Across all learning outcomes, there is remarkable consistency in findings that both genetic and environmental influences matter. However, much of this research is in its early stages, and while GWAS research and PGSs appear to promise new insights into both the genetic architectures and environmental influences on individual learning

Research funding should be allocated to cutting-edge studies examining the intersections of social, biological and psychological influences on learning and educational outcomes.

outcomes, there remain significant knowledge gaps regarding the underlying mechanisms at both the biological and environmental levels. Moreover, the policy relevance of such research remains unclear at best and highly controversial at worst. In particular, claims that it may be possible to personalize education, to address individual differences in students' genetic propensities for learning, are considered by most researchers to be based on misinterpretations and over-claims from the available evidence.

Psychological accounts of cognition, mindset, character and EF are all moving in the direction of more culturally sensitive conceptualizations that acknowledge the interaction of students' psychological and cognitive processes with environments and settings, including an attention to the political ideologies embedded in such approaches to enhancing learning.

Social science has begun to engage with the embodied, embrained, emotional and cognitive dimensions of learning, eschewing environmental determinism in favour of more nuanced engagements with genomics, neuroscience and psychology, whilst also developing novel understandings of the complex intersections of social, cultural, economic, environmental and political factors that shape individual differences.

Though these various disciplinary developments cannot and should not be collapsed together, they provide a compelling set of understandings of individual difference and its influence on learning. They highlight dynamic, bidirectional interactions, intersections and entwinements of bodies, minds and environments, and caution against narrow policy or practice interventions that focus on single assumed causal factors.

3.6 Recommendations

- Policy developments focused on individual differences related to learning and educational outcomes should acknowledge that these differences are the result of dynamic interactions between biological, psychological and social processes, not the simple effect of the intrinsic qualities of the individual.
- Research funding should be allocated to cutting-edge studies examining the intersections of social, biological and psychological influences on learning and educational outcomes. This would enable new multidisciplinary research knowledge to be produced detailing the effects of social contexts, physical environments and other socio-economic, political and material influences on individual differences related to learning.
- Future research and policy development in the field of education should aim to expand notions of individual difference and learning by facilitating multidisciplinary expert working groups consisting of representatives from the social, psychological and biological sciences. These expert working groups would develop new multidisciplinary research agenda leading to novel policy-relevant findings on the intersecting social, biological and psychological factors that influence individual differences in learning and educational outcomes.

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