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Viewing education policy through a genetic lens

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Abstract:	This paper introduces a literature from outside the field of education research and policy that we argue has potential to enhance both policy and practice. This field, behavioral genetics, has amassed highly replicable findings spanning more than half a century. Although no necessary policy implications follow from the evidence we review here, taking a 'genetic lens' may offer education researchers and policy-makers an opportunity to look at existing research in a fresh way; and to ask new questions and design new solutions. Incorporating evidence from behavioral genetics into interpretations of education and policy data can help researchers and decision makers better understand why some education policies have worked while others have not, and inform broader discussions of equality, fairness, and disadvantage in education.
Response to Reviewers:	Dear Professor Maranto, Re. Manuscript 195036835: Viewing education policy through a genetic lens We would like to thank you, and two reviewers, for your thoughtful and constructive reviews of our paper and for the opportunity to revise and resubmit it to Journal of School Choice. We have now had the opportunity to make the changes and additions suggested through the review process and hope that you will find the revised version of the manuscript suitable for publication. Our responses to the reviewers' comments are detailed below. Yours faithfully, Kathryn Asbury and Jonathan Wai Reviewer 1 Please add comments you don't mind the author seeing. I find the paper interesting and it discusses research that I was not aware of as someone who is generally knowledgeable about education. For the average reader, it would be helpful to provide more discussion of what behavioral genetics is. More importantly, it would improve the paper for a general reader if particular examples of how this research can be used to analyze educational policies. For example, information about how one might use the heritability data to examine the effectiveness of pre-school education. The author states that three are no policy implications from the research. I suspect that many readers are in fact looking for policy implications and as I noted, one example could be that one might look at empirical studies regarding the effectiveness of preschool programs differently given how heritability changes over time. The paper would be much improved by backing off on the no policy implications and discuss why this is useful knowledge for someone who is interested in improvements in the educational system. Thanks for this positive response to our paper, and for these constructive suggestions which we believe has made it stronger. We have now added more information on what behavioral genetics is. For instance, on p.2 of the revised manuscript we now say: The aim of behavioral genetics is to identify and understand the relative influence of genetic and environmental factors on human behavior, and the interplay between them. We have also given more specific examples of how genetically-informed data can be used to analyse particular education policies. We really like the suggestion of focusing

on the effectiveness of preschool programs – a clear and testable hypothesis (i.e., that heritability would increase as the preschool experience was standardized) but we were unaware of an existing US preschool policy to hang this on. However, we did take the advice more generally and we have added in discussions of curriculum policy and school choice, as well as policies focused on reducing the vocabulary gap or increasing 'grit' in school children. Some examples of this are detailed here, and more can be found in the revised manuscript.

Taking a finding such as Hart and Risley's (1995) finding regarding the number of words heard by a young child and their vocabulary without considering whether vocabulary knowledge and use is transmitted genetically, environmentally - or both – led to outrage about a '30 million word gap' between poor children and their middle class counterparts and a raft of rather patronising policies and charitable initiatives designed to teach economically poor parents how to speak to their children (Sperry, Sperry & Miller, 2019). Too much of developmental psychology makes the same assumption, that behavior is passed from parent to child environmentally, and behavioral genetic research undermines this assumption. (p.9)

Some U.S. education policy scholars have suggested that a more uniform knowledge-based curriculum would be beneficial for all students (e.g., Hirsch, 1988; Pondiscio, 2019). We note here that, to the extent to which the curriculum is made more uniform—whether Hirschian or not—we would expect it to lead to an increase in heritability because it would remove some of the environmental variance (curriculum differences between teachers and between schools) and ensure that all children had access to the same content. This could have implications for curricular and finance reform, among other areas of education policy. (p.12)

Thank you again for your constructive feedback. We hope you feel that this revised manuscript adequately addresses your concerns.

Reviewer 2

This review of behavioral genetic data as it relates to education is accurate, well-organized and well-written. The concluding section on policy was disappointing in the sense that it seemed to discuss generalities, not specific policy recommendations (e.g., 'ensure that all children have an equally diverse canteen of developmental opportunities', and 'consider cognitive and genetic indices of disadvantage as well as social and economic ones'). However, I suppose the authors are not to be faulted for this - it probably represents the state of the field at this time. Also, as the authors say, no necessary policy implications follow; however this seems to undercut the title of the paper, 'Viewing education policy through a genetics lens'.

We thank you for your positive comments on our paper. You will see from our response to Reviewer 1 that we have now revised the manuscript to address some more specific policy issues. However, for the reason you outline we have also built in a caveat. Behavioral genetic research can trigger somewhat emotional responses and we are very keen to start a useful discussion while not over-stating the implications of the research.

We fully understand many of those involved in education policy are eager to find solutions to implement and evaluate, and we have sought to provide tentative suggestions for the ways in which this information we reviewed here might provide a new way of looking at policy discussions and evidence. However, we note that psychologists (and even more so geneticists) are rightly cautious about ensuring there is a large amount of replicable evidence prior to importing findings into an applied area such as education policy. (pp.16-17)

Thank you again for your helpful input.

Viewing education policy through a genetic lens

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Abstract

This paper introduces a literature from outside the field of education research and policy that we argue has potential to enhance both policy and practice. This field, behavioral genetics, has amassed highly replicable findings spanning more than half a century. Although no necessary policy implications follow from the evidence we review here, taking a 'genetic lens' may offer education researchers and policy-makers an opportunity to look at existing research in a fresh way; and to ask new questions and design new solutions. Incorporating evidence from behavioral genetics into interpretations of education and policy data can help researchers and decision makers better understand why some education policies have worked while others have not, and inform broader discussions of equality, fairness, and disadvantage in education.

Introduction and problem definition

There is a large and robust body of evidence, gathered over the course of more than half a century, which offers powerful explanations for why children across the world, including the U.S., perform differently from each other in school (Polderman et al., 2015). This research comes from the field of behavioral genetics which uses twin, adoption and molecular genetic studies to understand the origins of individual differences in behavior (see

Knopik et al., 2016). The aim of behavioral genetics is to identify and understand the relative influence of genetic and environmental factors on human behavior, and the interplay between them. It is surprising, given its robustness, that this research has not been taken into account in the discussion or development of education policies, and that genetics is rarely mentioned as a limitation for a field often focused on potential confounds or endogenous factors (see Hart, Little, & van Bergen, 2019). It seems clear that evidence from behavioral genetics has not been successfully communicated to, or integrated into, the body of evidence used by education policy-makers. As a result, policy-makers have not had access to all relevant information when considering how children can best be supported in their learning. This is a problem for two main reasons: (1) education should be evidence-based if it is to be effective, as is already the case in medicine; and (2) behavioral genetic findings can shed light on why some policies or strategies have the potential to be effective while others do not.

In this brief review we present some key findings from behavioral genetics that are particularly salient to discussions of education policies and practices. We make a case that the science of genetics does not pose a threat to the education system. On the contrary, we argue that it has the potential to make education more efficient and equitable, and to guide additional resources to those who need them most. Our review of illustrative findings from twin studies and genome-wide association studies makes clear that genetic effects are not deterministic, and that not acknowledging genetically-informed explanations for individual differences in learning abilities and achievement can lead to sub-optimal policy decisions and sub-optimal experiences for children in schools. For instance, taking genetically influenced individual differences into account suggests that ‘one size fits all’ policies – such as free books for all pre-schoolers – are unlikely to be successful, particularly if the aim is to reduce variance in performance (‘the gap’) rather than to increase mean reading performance or school readiness. Our discussion of policy implications makes clear that no policies necessarily follow from this evidence-base but that awareness and understanding of it – and willingness to consider it alongside other sources of evidence – should enable better, more evidence-informed decision making. Furthermore, discussion of these findings will become essential as we respond to the challenges thrown up by recent developments in molecular genetics such as the identification and proliferation of polygenic risk scores (Lee at al., 2018; Plomin, 2018).

Review of the literature

Everything is heritable

At the outset, we emphasise that heritability tells us *what is* rather than *what can be* and in no way negates the importance of the environment. The 'first law of behavioral genetics' – that "everything is heritable" - was discussed almost thirty years ago (Turkheimer & Gottesman, 1991). This 'first law' was built on decades of twin, adoption and family studies that found universal heritability for behavioral traits, and 21st century research has continued to support this. Before describing some of the evidence underpinning the law it is important to briefly explain what is meant by the term 'heritability'.

Heritability is a population statistic that represents the extent to which individual differences in any trait are explained by genetic differences between individuals. As a population statistic it does not tell us anything specific about individuals, only about the differences between them (statistically speaking the variance). Heritability estimates can be calculated whenever individuals with different degrees of genetic relatedness such as monozygotic and dizygotic twins, or biological and adopted children, are compared. If genetically related individuals are more similar than non-genetically related individuals on an aspect of behavior (e.g., general cognitive ability or conscientiousness) this indicates that the behavior is to some extent heritable. Twin studies represent a natural experiment in that monozygotic twins share all of their genetic material while dizygotic twins share, on average, only half. These studies have found that monozygotic twins are more similar to each other than dizygotic twins on almost all behavioral traits (Plomin, Owen & McGuffin, 1994) and this pattern has been clear for several decades. It is important to note that heritability estimates are not fixed and can be different at different ages, in different countries and in different educational contexts. For instance, one Florida-based twin study found that reading ability was highly heritable when first graders were taught by a high-quality teacher but that heritability was significantly lower for children taught by a low-quality teacher (Taylor et al., 2010). A cross-cultural study found that the heritability of reading was high among Australian kindergartners with a state-mandated literacy curriculum, but low among Scandinavian children of the same age who received no formal literacy instruction (Samuelsson et al., 2008). However, after the Scandinavian children had been exposed to a year of formal literacy instruction the heritability of their reading ability increased just as dramatically as their illiteracy rate plummeted. In short, schools and teachers in both Australia and Scandinavia were the main reason that children learned to read but, once access to schools and teachers had been equalized, genetic differences were the main reason that some were better readers than others.

Perhaps the most dramatic example of heritability estimates changing over time relates to general cognitive ability. We know that cognitive ability is heritable, as predicted by the first law, and that the average heritability estimate across studies and countries is 50%, leaving the remaining variance to be explained by environmental factors and measurement error (Plomin & Deary, 2015). However, the story is in fact more interesting than this. The heritability of cognitive ability changes quite dramatically over the course of development, a pattern seen across countries. In the preschool years heritability is rather low but increases throughout childhood, and education, to an estimated 41% by age 9, 55% by age 12 and 66% by age 17 in the U.S., Australia, the Netherlands and the U.K. (Haworth et al., 2010). As children grow and have more opportunities to choose and influence their own experiences (a process known in the behavioral genetic literature as genotype-environment correlation), genetic differences explain an increasing proportion of differences in cognitive ability. This could have implications for early intervention programs because meaningful proportions of variance in cognitive ability are explained by environmental factors in early childhood but environmental explanations for these individual differences become increasingly unimportant as we age. It speaks to the likely benefit of good early intervention policies that support children in reaching a strong baseline by the time they enter kindergarten. Policies that affect children raised in the family in the same way are unlikely to have any meaningful impact on individual differences in cognitive ability after the preschool years. That said, it is important to remember that the environment can still drive mean-level change; an excellent intervention can move the entire normal distribution along to the right, even if it does not explain the curve or narrow the gap between its tails. It has been noted, for example, that going to school has a beneficial impact on general cognitive ability with small, incremental gains associated with each additional year of schooling (Ritchie & Tucker-Drob, 2018). Considering the purpose of an intervention is therefore important – increasing the average requires a different approach to narrowing the gap – and genetic evidence can provide useful information in considering the most effective approach.

Heritable cognitive ability is strongly correlated with academic achievement, the real bread and butter of education. Behavioral genetics has documented that achievement in school subjects is also heritable, and some studies have in fact found it to be even more heritable than cognitive ability (Kovas et al., 2013). The Twins Early Development Study (TEDS) is a U.K. based project that has followed a large sample of twins throughout their education, assessing their academic achievement every few years. Over this time a stable pattern of moderate to high heritability estimates, and modest to moderate shared environmental influences (factors that affect children in the same family in the same way), has emerged across ages and academic domains. In elementary school heritability estimates for English and Math hovered just above 60% for teacher-assessed English, Math and Science at ages seven, nine and twelve; and estimates of shared environmental influence were between 0 and 20% for English and Math at seven and nine, and almost 30% for Science between ages nine and twelve (Kovas, Haworth, Dale & Plomin, 2007). By the time the twins were 16, and taking public examinations, the heritability estimate for academic achievement in core subjects was 58%, so very similar to elementary school estimates, and shared environmental factors explained 29% of the variance (Krapohl, Rimfeld et al., 2014; Shakeshaft et al., 2013). By 18 heritability still explained 59% of the variance in achievement on average (Rimfeld et al., 2016). Similar patterns have been observed in the U.S. and elsewhere in Europe (de Zeeuw et al., 2015; Little, Haughbrook & Hart, 2016).

One striking element of these findings is that studies consistently find evidence of shared environmental effects on educational variables throughout the school years, with some exceptions such as Math and Chemistry at age 18 (Rimfeld et al., 2016). These shared environmental factors represent between family effects, potentially including home and family influences (e.g., parental support and family resources); school influences (e.g., inequalities in teaching quality or resources between schools); or neighborhood effects (e.g., crime or access to libraries). It is likely that substantial shared environmental variance is indicative of some type of 'genuinely environmental' inequality, an important issue for social policy to address that merits much more discussion than it has received, and requires controlling for genetic effects. Identifying shared environmental effects, difficult to untangle in the classical twin design, will be an important priority as developments in molecular genetics continue to bear fruit. This stands out as a particularly important consideration for educational policy-makers who want to reduce inequity in education. Evidence of notable shared environmental effects can potentially be used as 'hot spot' guides for policies focused on reducing environmental inequality but we need to learn more about the specific experiences that explain the shared environmental component of variance to support this. In summary, we know that both ability and achievement are heritable at all stages of compulsory formal education, and across domains, and this is therefore important to consider when allocating resources and developing policies designed to support and nurture educational achievement.

We know too that making the decision to pursue higher education (51%); choosing a high quality college (57%); getting in to that college (57%) and achievement once you get there (46%) are also heritable, as indicated by the heritability estimates presented in parentheses (Smith-Woolley et al., 2018). For most of these university 'success' variables shared environmental factors explained little variance, suggesting that heritable characteristics and non-shared or random happenings drive these experiences. However, this was not the case for university enrolment where shared environmental factors explained almost half of the variance. Again, this indicates inequality of opportunity in that the decision to go to university appears to be influenced almost as much by family-wide factors as it is by individual characteristics such as ability, prior achievement and motivation. It is a good example of how genetic research can shine a light on areas of social injustice. Correcting for genetic effects adds a new nuance to important social policy questions and allows us to work towards a better understanding of environmental mechanisms. It suggests that more work is needed to promote the benefits of higher education to young people growing up in disadvantaged families.

A further point to note in making the case that ‘everything is heritable’ is that variables traditionally considered to be environmental, such as socio-economic status (SES), have also been found to be partly heritable, with approximately half of the variance in SES explained by DNA differences between individuals (Branigan, McCallum & Freese, 2013). This phenomenon is usually referred to as ‘the nature of nurture’ (Plomin & Bergeman, 1991). Therefore, in understanding how experience influences outcomes – particularly if the aim of that understanding is to maximise the positive impact of experience (e.g., school effects) – then it is vital to take the role of genes into account. If ‘everything is heritable’ then it seems unreasonable not to consider the implications of the heritability of behavior and experience in planning for the optimal deployment of education.

Nature via Nurture

We have described how heritability estimates only apply to a particular sample, place, and time and can be moderated by age and context. This makes clear that genes are rarely deterministic (single gene disorders such as Huntington’s disease being the exception) and that genotypes are dependent on the environmental circumstances in which an individual engages for behavioral expression. Policy-makers and school leaders have a vital role to play, therefore, in optimising the canteen of educational opportunities – the environmental circumstances – that each genotype, each child, will encounter. Genotype-environment interplay research clearly highlights this. If some children and young people find academic work more challenging and less engaging than others, partly for biological reasons, then it seems important to offer an education that can nurture their strengths and preferences as well as providing them with at least the minimum level of academic learning required to function effectively in society. If school rewards academic achievement above all else then it is bound to alienate some of those it exists to nurture, including the most vulnerable students.

Not controlling for the effect of genes in education or socialization research renders findings uninterpretable as it becomes impossible to ask whether a policy or practice works, or does not work, for truly environmental reasons. For example, taking Hart and Risley's (1995) finding regarding the number of words heard by a young child and their vocabulary without considering whether vocabulary knowledge and use is transmitted genetically, environmentally – or both – led to outrage about a '30 million word gap' between poor children and their middle class counterparts and a raft of policies and charitable initiatives designed to teach economically poor parents how to speak to their children (Sperry, Sperry & Miller, 2019). Too much of developmental psychology makes the same assumption, that behavior is passed from parent to child environmentally, and behavioral genetic research undermines this assumption. Another good example relates to the recent popularity within education of psychological constructs such as grit (Duckworth & Quinn, 2009). Because most of the research on which grit is based is not genetically-informed, it is unclear whether the narrative surrounding it, and related constructs such as growth mindset, is valid (for additional critiques, see Crede, 2018; Sisk et al., 2018; Whitehurst, 2019). In fact research shows that grit is heritable (e.g., Lee & Wiggins, 2015; Rimfeld, Kovas, Dale & Plomin, 2016) and that it is almost indistinguishable from conscientiousness. Distinguishing grit from conscientiousness would, we argue, might be possible by incorporating passion into the scale – passion is a key element of the grit narrative but not of its measurement – and it would indeed be interesting to explore the heritability of how children and young people identify passions which they are motivated to persevere with in a genetically sensitive design, with clear implications for vocational education. However, whether the new passion scale is nonredundant from conscientiousness or other established constructs would still need to be carefully evaluated.

A focus on genotype-environment correlation (rge) is needed. There are three types of rge that were clearly laid out in a landmark paper over 40 years ago (Plomin et al., 1977). In a *passive rge* parents pass on their genes to their children but also create their environments, both of which feed into the child's behavior. So, parents with a genetic predisposition to enjoy and be good at reading will pass on those genes to their children but will also curate an environment for their children that is likely to be 'reading friendly'. This puts their children at an advantage compared to a family wherein the parents are genetically predisposed to find reading difficult, and therefore do not enjoy it, and who also create a home with fewer opportunities for reading development. The inequity here exists for both genetic and environmental reasons, which are clearly linked to each other. Not understanding passive genotype-environment correlation leads to policies with low chances of success such as buying books for disadvantaged families as a standalone policy. This sort of approach is likely to waste money and resources by not understanding that a lack of books is most likely driven by parent- and child-genotypes, rather than, simply, by economic circumstances. The two other types of rge to consider are *evocative rge* (in which people respond to a child on the basis of his or her inherited characteristics) and *active rge* (in which a child seeks out certain experiences - libraries, sports teams, friendship groups etc.) on the basis of their inherited characteristics (Scarr & McCartney, 1983). In all of these instances, genotypes drive experiences and a clear understanding of the possible implications of this raises challenges for education policy-making and resourcing decisions.

The other major type of genotype-environment interplay has a moderating (rather than a mediating) effect and is known as Genotype (or Gene) x Environment Interaction (GxE). The study described earlier, in which the heritability of reading among Florida school children was higher for those taught by higher quality teachers is an example of GxE. Another illustrative example was reported by Turkheimer and colleagues (2003) who found the heritability of cognitive ability to be significantly lower for children in disadvantaged families compared to those in affluent families. For children in disadvantaged families, shared environmental factors explained around 60% of individual differences in U.S. seven-year-olds, with DNA differences explaining almost no variance, while this pattern was reversed in children from wealthier families. This is a highly cited finding but perhaps the most interesting element is that the pattern does not replicate elsewhere in the world (Tucker-Drob & Bates, 2016). The suppression of heritability in disadvantaged environments appears to be a U.S. phenomenon (although not all U.S. based studies have supported it: e.g., Figlio et al., 2017). This raises interesting questions about the U.S. system of education and about why the heritability of cognitive ability for children from poor families might be reduced in the U.S. but not elsewhere. One likely explanation is the greater diversity of educational input in the U.S. than in Europe and Australia where National Curricula are commonplace. In countries with a National Curriculum every child has access to approximately the same education, and is tested on the same material, regardless of their geographical location or economic circumstances. This removes variance that could be explained by curriculum-related inequalities, leaving relative achievement to be better explained by individual characteristics. This has led some to suggest that heritability could be viewed as an index of equality (e.g., Plomin, 2018). This counter-intuitive idea is based on an understanding that if students have genuinely equal environments, then environmental factors will not be able to explain individual differences (because they will not differ between individuals). We might expect that individual differences would be reduced (as environmental inequality was eliminated) and therefore any remaining variation (which would still be substantial) would be explained by genetic factors and chance events. In an equal society everybody would have the opportunity to fully access environments that supported their personal needs, abilities and preferences and we would be left with behavioral differences primarily explained by DNA differences. While the idea of genetic inequality is not necessarily much less problematic than the idea of a society built on social inequities and injustices, it is an argument that has an important place in any debate about equality and social justice in education.

Some U.S. education policy scholars have suggested that a more uniform knowledge-based curriculum would be beneficial for all students (e.g., Hirsch, 1988; Pondiscio, 2019). We note here that, to the extent to which the curriculum is made more uniform – whether Hirschian or not – we would expect it to lead to an increase in heritability because it would remove some of the environmental variance (curriculum differences between teachers and between schools) and ensure that all children had access to the same content. This could have implications for curricular and finance reform, among other areas of education policy.

In sum then, over a half century of broadly replicated evidence from the field of behavioral genetics has made clear that accepting the importance of genetic influences on educational outcomes, and working to better understand the interface between genes and experiences, should have a profound impact on policy discussions and should lead to a focus on individual differences as well as a focus on averages (Martschenko, Trejo, & Domingue, 2019). A case can be made that not doing so poses a threat to the likelihood of identifying the types of educational opportunities that can help students most.

Polygenic Risk Scores and the speed of Science

Until recent years behavioral genetics was often criticized for its ‘missing heritability problem’ (e.g., Maher, 2008; Plomin, 2013). This problem referred to the fact that while twin and adoption studies had identified moderate to substantial heritability estimates for a diverse array of behavioral traits, very few actual genetic variants had been found to explain or justify the heritability estimates. In the last few years, however, we have witnessed what has been termed a ‘DNA Revolution’ (Plomin, 2018). As one failed attempt to find genes associated with behavior followed another it became increasingly clear to the genetics community that behavior was likely to be explained by many genetic variants of individually miniscule effect. The main challenge associated with identifying alleles with vanishingly small effects was one of statistical power. Thus began the push to combine samples from around the world in order to find the relevant genes. In 2016 the Social Science Genetic Association Consortium conducted a genome-wide association study (GWAS) with an international sample of almost 300,000 participants in an attempt to find specific genetic variants associated with years of education (Okbay et al., 2016). They found 74 such variants, which they combined into a polygenic score known as EduYears. Their achievement represented a major step forward as a previous attempt with a sample of just over 100,000 participants had only identified three such genetic variants, all of which replicated in this new study (Rietveld et al., 2013) and suggested that the notion that all that was stopping scientists from identifying educationally-relevant genetic variants was sample size and statistical power was correct. Because of the small individual contribution such variants make it is sensible to combine them in polygenic scores with the potential for meaningful prediction. This was an enormous success story. However, EduYears was only able to explain approximately 4% of the variance in years of education. Policy-makers can be forgiven for not getting particularly excited about this, especially given the unsophisticated nature of the outcome variable. This was very clearly work in progress. However, this progress has continued apace and it is now time to take notice. In summer 2018 the third version of this polygenic score, known as EA3, was generated on the basis of data from 1.1 million participants and is made up of over 1000 individual genetic variants (Lee et al., 2018). EA3 explains 11-13% of individual differences in years of school, and 7-10% of individual differences in cognitive ability. One U.K. study found that EA3 predicted 14% of the variance in educational achievement at age 16 (von Stumm et al., 2019). At the same stage SES explained 23% of the variance but, after controlling for genetic influences on SES it explained 16% of individual differences in academic performance. EA3 can therefore be considered as being roughly equivalent to SES as a driver of individual differences in academic performance. We also know that EA3 becomes increasingly powerful as a predictor over time, as suggested by earlier research on the increasing heritability of cognitive ability over time (Allegrini et al., 2018). The explanatory power of polygenic scores, at the population level, has become meaningful and poses questions for education which need to be rigorously and sensitively explored. EA3 explains as much variance as some measures of family income and this raises the question of whether a low EA3 score can be considered as an indicator of disadvantage in the same way as low family income and, if so, what can and should be done about that?

Implications for policy and practice

It is important to reiterate that, although this body of research is highly robust and replicated, no necessary policy implications follow from it and, indeed, it raises more questions than solutions at this point. The questions it raises are important and merit widespread discussion, as well as the re-reading – and perhaps attempt at replication – of some educational research using a ‘genetic lens’. Policy solutions within European countries may be different than in the U.S. which may have different debates and concerns (e.g., Henderson et al., 2019). This may, or may not, lead to new ways of doing things, but should at least inform the body of evidence used in decision making. Our aim in this paper has been to introduce key illustrative studies and to make a case that education policies and practices, along with educational research, can be informed by this research. In this concluding section we briefly outline some of the areas of policy, and discussions, that behavioral genetic research could potentially make a meaningful contribution to. These are speculative and policy-makers and educational policy researchers may well identify other areas where the 'genetic lens' has more to offer. We focus on two sets of possible implications that exemplify how this might work. The first is rooted in Scarr & McCartney's (1983) Theory of Genotype → Environment Effects and has implications for policies related to supporting individual differences via student choice, and providing equal opportunities to all. The second concerns how we define disadvantage and the policies that flow from this.

If genotypes drive experiences then, in a perfectly equal world, everything should be close to 100% heritable. This is not the case for many reasons. One of these reasons is that non-shared environmental factors (idiosyncratic, or chance, experiences that are uncorrelated with genetic effects and include measurement error) explain some variance and will continue to do so even in the most equal of societies. Scarr and McCartney (1983) explain how, outside of these more random occurrences, genes drive experiences. However, if a child has the genetic propensity to become a jockey but grows up in a home without access to horses this is unlikely to happen. Equally, if a child has a propensity to thrive in higher education but grows up in a home – or is educated in a school – where this is not the expectation for a 'child like him' then his genotype may be denied the opportunity to drive his experience (making space for shared environmental effects, as noted above). Policy-makers are in a position to support the process of genotype-environment correlation by ensuring that all children have an equally diverse canteen of developmental opportunities to choose from. Alongside the provision of such opportunities it is clear that barriers to accessing them – which could include finances, transportation, disability and home circumstances – will need to be addressed. One aspect of U.S. education policy this may be linked to is the discussion over school choice (e.g., Diperna, 2019; Wolf, 2018).

The literature on behavioral genetics is largely focused on asking “reverse causal questions” rather than questions about “forward causal inference” (Wai & Bailey, in press). Reverse causal questions are those about the unknown causes of known effects. Forward causal inference—the approach typically taken by many education policy researchers—focuses on estimating the unknown effects of known causes (Gelman & Imbens, 2013). We note that there is a broad literature—spanning psychological individual differences to education policy—suggesting that the vast majority of student achievement outcomes are due to student traits or characteristics (see Detterman, 2016, for a review), which are heritable, whereas a much smaller portion of student achievement variance is due to teachers or schools (e.g., Gibbons & Silva, 2011; Whitehurst, Chingos, & Gallaher, 2013), in particular within genetically sensitive designs (Grasby et al., 2019). We clarify that although more discussion in education policy should surround the fact that most of student achievement and long-term outcome variance is due to student characteristics, there is also a large body of rigorous research by many policy researchers focusing on estimating the unknown effects of known causes, including in the area of school choice (e.g., Wolf, 2019), and that these two approaches are complimentary (Wai & Bailey, in press).

In terms of how we define and respond to disadvantage it is worth considering whether, in a world in which a polygenic score for educational attainment has as much predictive power as some measures of family income, we need to consider cognitive and genetic indices of disadvantage as well as social and economic ones. We argue that it is important to consider whether policies designed to compensate for disadvantage should also take such indices into account, and what the practical and ethical implications of doing so would be. This would require better understanding how people might see as the risks and benefits of using this information.

We fully understand many of those involved in education policy are eager to find solutions to implement and evaluate, and we have sought to provide tentative suggestions for the ways in which this information we reviewed here might provide a new way of looking at policy discussions and evidence. However, we note that psychologists (and even more so geneticists) are rightly cautious about ensuring there is a large amount of replicable evidence prior to importing findings into an applied area such as education policy. The evidence from the field of behavioral genetics is one of the most robust literatures that has amassed across the last half century (Polderman et al., 2015). And yet, we still urge caution in applying these findings to education policy contexts. In that sense, we also urge education policymakers to more deeply consider the strength of evidence surrounding psychological or other constructs prior to importing them into far-reaching interventions, and to update their expectations for efficacy based on the ongoing updating of the psychological and behavioral genetic research literature (e.g., Open Science Collaboration, 2015).

Conclusions

In conclusion we argue that there is strong reason to believe that education policy and practice can be enhanced by including evidence from behavioral genetics and individual differences. While no necessary policy implications follow from the evidence, the large research base supporting the ‘genetic lens’ offers policy-makers an opportunity to take a new, evidence-based perspective on why some specific policies have worked whereas others have not, and to inform broader discussions of equality, fairness and disadvantage in education.

References

Allegrini, A., Selzam, S., Rimfeld, K., von Stumm, S., Pingault, J. B., & Plomin, R. (2018). Genomic prediction of cognitive traits in childhood and adolescence. *bioRxiv*, 418210.

Branigan, A. R., McCallum, K. J., & Freese, J. (2013). Variation in the heritability of educational attainment: An international meta-analysis. *Social forces*, *92*, 109-140.

de Zeeuw, E. L., de Geus, E. J., & Boomsma, D. I. (2015). Meta-analysis of twin studies highlights the importance of genetic variation in primary school educational achievement. *Trends in Neuroscience and Education*, *4*, 69-76.

Crede, M. (2018). What shall we do about grit? A critical review of what we know and we don't know. *Educational Researcher, 47,* 606-611.

Detterman, D. K. (2016). Pity the poor teacher because student characteristics are more significant than teachers or schools. *Spanish Journal of Psychology, 19*, E93.

Diperna, P. (2019). 2019 schooling in America survey. *Ed Choice*. Retrieved from: https://www.edchoice.org/research/2019-schooling-in-america-survey/

Duckworth, A. L., & Quinn, P. D. (2009). Development and validation of the Short Grit Scale (GRIT–S). *Journal of personality assessment*, *91*(2), 166-174.

Figlio, D. N., Freese, J., Karbownik, K., & Roth, J. (2017). Socioeconomic status and genetic influences on cognitive development. *Proceedings of the National Academy of Sciences*, *114*, 13441-13446.

Gelman, A., & Imbens, G. (2013). Why ask why? Forward causal inference and reverse causal questions. *NBER Working Paper 19614:* https://www.nber.org/papers/w19614

Gibbons, S., & Silva, O. (2011). School quality, child wellbeing and parents' satisfaction. *Economics of Education Review, 30,* 312-331.

Grasby, K. L., Little, C. W., Byrne, B., Coventry, W. L., Olson, R. K., & Larsen, S. (2019). Estimating classroom-level influences on literacy and numeracy: A twin study. *Journal of Educational Psychology*. Advance online publication.

Hart, S. A., Little, C., & van Bergen, E. (2019). Nurture might be nature: Cautionary tales and proposed solutions. *PsArXiv Preprint*. Retrieved from: https://psyarxiv.com/j5x7g/

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Paul H Brookes Publishing.

Haworth, C. M., Wright, M. J., Luciano, M., Martin, N. G., de Geus, E. J., van Beijsterveldt, C. E., ... & Kovas, Y. (2010). The heritability of general cognitive ability increases linearly from childhood to young adulthood. *Molecular psychiatry*, *15*(, 1112 - 1120.

Henderson, M. B., Houston, D., Peterson, P. E., & West, M. R. (2019). Public support grows for higher teacher pay and expanded school choice. *Education Next, 20*. Retrieved from: https://www.educationnext.org/school-choice-trump-era-results-2019-education-next-poll/

Hirsch, E. D. (1988). *Cultural literacy: What every American needs to know*. New York, NY: Vintage.

Knopik, V. S., Neiderhiser, J. M., DeFries, J. C., & Plomin, R. (2016). *Behavioral genetics*. Macmillan Higher Education.

Kovas, Y., Haworth, C. M., Dale, P. S., & Plomin, R. (2007). The genetic and environmental origins of learning abilities and disabilities in the early school years. *Monographs of the Society for research in Child Development*, *72*, vii-1.

Kovas, Y., Voronin, I., Kaydalov, A., Malykh, S. B., Dale, P. S., & Plomin, R. (2013). Literacy and numeracy are more heritable than intelligence in primary school. *Psychological science*, *24*, 2048-2056.

Krapohl, E., Rimfeld, K., Shakeshaft, N. G., Trzaskowski, M., McMillan, A., Pingault, J. B., ... & Plomin, R. (2014). The high heritability of educational achievement reflects many genetically influenced traits, not just intelligence. *Proceedings of the National Academy of Sciences*, *111*, 15273-15278.

Lee, J. J., Wedow, R., Okbay, A., Kong, E., Maghzian, O., Zacher, M., ... & Fontana, M. A. (2018). Gene discovery and polygenic prediction from a genome-wide association study of educational attainment in 1.1 million individuals. *Nature genetics*, *50*, 1112.

Lee, J., & Wiggins, K. (2015). Growth mindset theory is ‘overplayed’ and could be harmful, geneticist warns. *Times Educational Supplement*. Retrieved from: https://www.tes.com/news/growth-mindset-theory-overplayed-and-could-be-harmful-geneticist-warns

Little, C. W., Haughbrook, R., & Hart, S. A. (2017). Cross-study differences in the etiology of reading comprehension: A meta-analytical review of twin studies. *Behavior genetics*, *47*, 52-76.

Maher, B. (2008). Personal genomes: The case of the missing heritability. *Nature News*, *456*, 18-21.

Martschenko, D., Trejo, S., & Domingue, B. W. (2019). Genetics and Education: Recent developments in the context of an ugly history and an uncertain future. *AERA Open*, *5*, 2332858418810516.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science, 349,* aac4716.

Okbay, A., Beauchamp, J. P., Fontana, M. A., Lee, J. J., Pers, T. H., Rietveld, C. A., ... & Oskarsson, S. (2016). Genome-wide association study identifies 74 loci associated with educational attainment. *Nature*, *533*, 539.

Plomin, R. (2013). Commentary: Missing heritability, polygenic scores, and gene–environment correlation. *Journal of Child Psychology and Psychiatry*, *54*, 1147-1149.

Plomin, R. (2018). *Blueprint: How DNA makes us who we are*. MIT Press.

Plomin, R., & Bergeman, C. S. (1991). The nature of nurture: Genetic influence on “environmental” measures. *Behavioral and Brain Sciences*, *14*, 373-386.

Plomin, R., & Deary, I. J. (2015). Genetics and intelligence differences: five special findings. *Molecular psychiatry*, *20*, 98 - 108.

Plomin, R., DeFries, J. C., & Loehlin, J. C. (1977). Genotype-environment interaction and correlation in the analysis of human behavior. *Psychological bulletin*, *84*, 309 - 322.

Plomin, R., Owen, M. J., & McGuffin, P. (1994). The genetic basis of complex human behaviors. *Science*, *264*, 1733-1739.

Polderman, T. J., Benyamin, B., De Leeuw, C. A., Sullivan, P. F., Van Bochoven, A., Visscher, P. M., & Posthuma, D. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. *Nature genetics*, *47*, 702-709.

Pondiscio, R. (2019). *How the other half learns: Equality, excellence, and the battle over school choice*. New York, NY: Avery.

Rietveld, C. A., Medland, S. E., Derringer, J., Yang, J., Esko, T., Martin, N. W., ... & Albrecht, E. (2013). GWAS of 126,559 individuals identifies genetic variants associated with educational attainment. *science*, *340*, 1467-1471.

Rimfeld, K., Ayorech, Z., Dale, P. S., Kovas, Y., & Plomin, R. (2016). Genetics affects choice of academic subjects as well as achievement. *Scientific reports*, *6*, 26373.

Rimfield, K., Kovas, Y., Dale, P. S., & Plomin, R. (2016). True grit and genetics: Predicting academic achievement from personality. *Journal of Personality and Social Psychology, 111,* 780-789.

Ritchie, S. J., & Tucker-Drob, E. M. (2018). How much does education improve intelligence? A meta-analysis. *Psychological science*, *29*, 1358-1369.

Samuelsson, S., Byrne, B., Olson, R. K., Hulslander, J., Wadsworth, S., Corley, R., ... & DeFries, J. C. (2008). Response to early literacy instruction in the United States, Australia, and Scandinavia: A behavioral-genetic analysis. *Learning and individual differences*, *18*, 289-295.

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype→ environment effects. *Child development, 54*, 424-435.

Shakeshaft, N. G., Trzaskowski, M., McMillan, A., Rimfeld, K., Krapohl, E., Haworth, C. M., ... & Plomin, R. (2013). Strong genetic influence on a UK nationwide test of educational achievement at the end of compulsory education at age 16. *PloS one*, *8*, e80341.

Sisk, V. F., Burgoyne, A. P., Sun, J., Butler, J. L., & Macnamara, B. N. (2018). To what extent and under which circumstances are growth mindsets important to academic achievement? Two meta-analyses. *Psychological Science, 29,* 549-571.

Smith-Woolley, E., Ayorech, Z., Dale, P. S., von Stumm, S., & Plomin, R. (2018). The genetics of university success. *Scientific reports*, *8*, 14579.

Sperry, D. E., Sperry, L. L., & Miller, P. J. (2019). Reexamining the verbal environments of children from different socioeconomic backgrounds. *Child development*, *90*, 1303-1318.

Taylor, J., Roehrig, A. D., Hensler, B. S., Connor, C. M., & Schatschneider, C. (2010). Teacher quality moderates the genetic effects on early reading. *Science*, *328*, 512-514.

Tucker-Drob, E. M., & Bates, T. C. (2016). Large cross-national differences in gene× socioeconomic status interaction on intelligence. *Psychological Science*, *27*, 138-149.

Turkheimer, E., & Gottesman, I. I. (1991). Is H 2= 0 a null hypothesis anymore?. *Behavioral and Brain Sciences*, *14*, 410-411.

Turkheimer, E., Haley, A., Waldron, M., d'Onofrio, B., & Gottesman, I. I. (2003). Socioeconomic status modifies heritability of IQ in young children. *Psychological science*, *14*, 623-628.

von Stumm, S., Smith-Woolley, E., Ayorech, Z., McMillan, A., Rimfeld, K., Dale, P., & Plomin, R. (2019). Predicting educational achievement from genomic measures and socioeconomic status. *bioRxiv*, 538108.

Wai, J., & Bailey, D. (in press). How intelligence research can inform education and public policy. To be published in A. K. Barbey, S. Karama, & R. J. Haier (Eds), *The Cambridge Handbook of Intelligence and Cognitive Neuroscience*. Retrieved from: https://www.researchgate.net/publication/335798156_How_Intelligence_Research_Can_Inform_Education_and_Public_Policy

Whitehurst, G. J. (2019). A prevalence of "policy-based evidence-making". *Education Next, 19*. Retrieved from: https://www.educationnext.org/prevalence-policy-based-evidence-making-forum-should-schools-embrace-social-emotional-learning/

Whitehurst, G. J., Chingos, M. M., & Gallaher, M. R. (2013). Do school districts matter? *Brookings Institution*. Retreived from: https://www.brookings.edu/research/do-school-districts-matter/

Wolf, P. (Ed.) (2019). *School choice: Separating fact from fiction*. New York, NY: Routledge.

Viewing education policy through a genetic lens

Abstract

This paper introduces a literature from outside the field of education research and policy that we argue has potential to enhance both policy and practice. This field, behavioral genetics, has amassed highly replicable findings spanning more than half a century. Although no necessary policy implications follow from the evidence we review here, taking a ‘genetic lens’ may offer education researchers and policy-makers an opportunity to look at existing research in a fresh way; and to ask new questions and design new solutions. Incorporating evidence from behavioral genetics into interpretations of education and policy data can help researchers and decision makers better understand why some education policies have worked while others have not, and inform broader discussions of equality, fairness, and disadvantage in education.

Introduction and problem definition

There is a large and robust body of evidence, gathered over the course of more than half a century, which offers powerful explanations for why children across the world, including the U.S., perform differently from each other in school (Polderman et al., 2015). This research comes from the field of behavioral genetics which uses twin, adoption and molecular genetic studies to understand the origins of individual differences in behavior (see Knopik et al., 2016). The aim of behavioral genetics is to identify and understand the relative influence of genetic and environmental factors on human behavior, and the interplay between them. It is surprising, given its robustness, that this research has not been taken into account in the discussion or development of education policies, and that genetics is rarely mentioned as a limitation for a field often focused on potential confounds or endogenous factors (see Hart, Little, & van Bergen, 2019). It seems clear that evidence from behavioral genetics has not been successfully communicated to, or integrated into, the body of evidence used by education policy-makers. As a result, policy-makers have not had access to all relevant information when considering how children can best be supported in their learning. This is a problem for two main reasons: (1) education should be evidence-based if it is to be effective, as is already the case in medicine; and (2) behavioral genetic findings can shed light on why some policies or strategies have the potential to be effective while others do not.

In this brief review we present some key findings from behavioral genetics that are particularly salient to discussions of education policies and practices. We make a case that the science of genetics does not pose a threat to the education system. On the contrary, we argue that it has the potential to make education more efficient and equitable, and to guide additional resources to those who need them most. Our review of illustrative findings from twin studies and genome-wide association studies makes clear that genetic effects are not deterministic, and that not acknowledging genetically-informed explanations for individual differences in learning abilities and achievement can lead to sub-optimal policy decisions and sub-optimal experiences for children in schools. For instance, taking genetically influenced individual differences into account suggests that ‘one size fits all’ policies – such as free books for all pre-schoolers – are unlikely to be successful, particularly if the aim is to reduce variance in performance (‘the gap’) rather than to increase mean reading performance or school readiness. Our discussion of policy implications makes clear that no policies necessarily follow from this evidence-base but that awareness and understanding of it – and willingness to consider it alongside other sources of evidence – should enable better, more evidence-informed decision making. Furthermore, discussion of these findings will become essential as we respond to the challenges thrown up by recent developments in molecular genetics such as the identification and proliferation of polygenic risk scores (Lee at al., 2018; Plomin, 2018).

Review of the literature

Everything is heritable

At the outset, we emphasise that heritability tells us *what is* rather than *what can be* and in no way negates the importance of the environment. The 'first law of behavioral genetics' – that "everything is heritable" - was discussed almost thirty years ago (Turkheimer & Gottesman, 1991). This 'first law' was built on decades of twin, adoption and family studies that found universal heritability for behavioral traits, and 21st century research has continued to support this. Before describing some of the evidence underpinning the law it is important to briefly explain what is meant by the term 'heritability'.

Heritability is a population statistic that represents the extent to which individual differences in any trait are explained by genetic differences between individuals. As a population statistic it does not tell us anything specific about individuals, only about the differences between them (statistically speaking the variance). Heritability estimates can be calculated whenever individuals with different degrees of genetic relatedness such as monozygotic and dizygotic twins, or biological and adopted children, are compared. If genetically related individuals are more similar than non-genetically related individuals on an aspect of behavior (e.g., general cognitive ability or conscientiousness) this indicates that the behavior is to some extent heritable. Twin studies represent a natural experiment in that monozygotic twins share all of their genetic material while dizygotic twins share, on average, only half. These studies have found that monozygotic twins are more similar to each other than dizygotic twins on almost all behavioral traits (Plomin, Owen & McGuffin, 1994) and this pattern has been clear for several decades. It is important to note that heritability estimates are not fixed and can be different at different ages, in different countries and in different educational contexts. For instance, one Florida-based twin study found that reading ability was highly heritable when first graders were taught by a high-quality teacher but that heritability was significantly lower for children taught by a low-quality teacher (Taylor et al., 2010). A cross-cultural study found that the heritability of reading was high among Australian kindergartners with a state-mandated literacy curriculum, but low among Scandinavian children of the same age who received no formal literacy instruction (Samuelsson et al., 2008). However, after the Scandinavian children had been exposed to a year of formal literacy instruction the heritability of their reading ability increased just as dramatically as their illiteracy rate plummeted. In short, schools and teachers in both Australia and Scandinavia were the main reason that children learned to read but, once access to schools and teachers had been equalized, genetic differences were the main reason that some were better readers than others.

Perhaps the most dramatic example of heritability estimates changing over time relates to general cognitive ability. We know that cognitive ability is heritable, as predicted by the first law, and that the average heritability estimate across studies and countries is 50%, leaving the remaining variance to be explained by environmental factors and measurement error (Plomin & Deary, 2015). However, the story is in fact more interesting than this. The heritability of cognitive ability changes quite dramatically over the course of development, a pattern seen across countries. In the preschool years heritability is rather low but increases throughout childhood, and education, to an estimated 41% by age 9, 55% by age 12 and 66% by age 17 in the U.S., Australia, the Netherlands and the U.K. (Haworth et al., 2010). As children grow and have more opportunities to choose and influence their own experiences (a process known in the behavioral genetic literature as genotype-environment correlation), genetic differences explain an increasing proportion of differences in cognitive ability. This could have implications for early intervention programs because meaningful proportions of variance in cognitive ability are explained by environmental factors in early childhood but environmental explanations for these individual differences become increasingly unimportant as we age. It speaks to the likely benefit of good early intervention policies that support children in reaching a strong baseline by the time they enter kindergarten. Policies that affect children raised in the family in the same way are unlikely to have any meaningful impact on individual differences in cognitive ability after the preschool years. That said, it is important to remember that the environment can still drive mean-level change; an excellent intervention can move the entire normal distribution along to the right, even if it does not explain the curve or narrow the gap between its tails. It has been noted, for example, that going to school has a beneficial impact on general cognitive ability with small, incremental gains associated with each additional year of schooling (Ritchie & Tucker-Drob, 2018). Considering the purpose of an intervention is therefore important – increasing the average requires a different approach to narrowing the gap – and genetic evidence can provide useful information in considering the most effective approach.

Heritable cognitive ability is strongly correlated with academic achievement, the real bread and butter of education. Behavioral genetics has documented that achievement in school subjects is also heritable, and some studies have in fact found it to be even more heritable than cognitive ability (Kovas et al., 2013). The Twins Early Development Study (TEDS) is a U.K. based project that has followed a large sample of twins throughout their education, assessing their academic achievement every few years. Over this time a stable pattern of moderate to high heritability estimates, and modest to moderate shared environmental influences (factors that affect children in the same family in the same way), has emerged across ages and academic domains. In elementary school heritability estimates for English and Math hovered just above 60% for teacher-assessed English, Math and Science at ages seven, nine and twelve; and estimates of shared environmental influence were between 0 and 20% for English and Math at seven and nine, and almost 30% for Science between ages nine and twelve (Kovas, Haworth, Dale & Plomin, 2007). By the time the twins were 16, and taking public examinations, the heritability estimate for academic achievement in core subjects was 58%, so very similar to elementary school estimates, and shared environmental factors explained 29% of the variance (Krapohl, Rimfeld et al., 2014; Shakeshaft et al., 2013). By 18 heritability still explained 59% of the variance in achievement on average (Rimfeld et al., 2016). Similar patterns have been observed in the U.S. and elsewhere in Europe (de Zeeuw et al., 2015; Little, Haughbrook & Hart, 2016).

One striking element of these findings is that studies consistently find evidence of shared environmental effects on educational variables throughout the school years, with some exceptions such as Math and Chemistry at age 18 (Rimfeld et al., 2016). These shared environmental factors represent between family effects, potentially including home and family influences (e.g., parental support and family resources); school influences (e.g., inequalities in teaching quality or resources between schools); or neighborhood effects (e.g., crime or access to libraries). It is likely that substantial shared environmental variance is indicative of some type of ‘genuinely environmental’ inequality, an important issue for social policy to address that merits much more discussion than it has received, and requires controlling for genetic effects. Identifying shared environmental effects, difficult to untangle in the classical twin design, will be an important priority as developments in molecular genetics continue to bear fruit. This stands out as a particularly important consideration for educational policy-makers who want to reduce inequity in education. Evidence of notable shared environmental effects can potentially be used as ‘hot spot’ guides for policies focused on reducing environmental inequality but we need to learn more about the specific experiences that explain the shared environmental component of variance to support this. In summary, we know that both ability and achievement are heritable at all stages of compulsory formal education, and across domains, and this is therefore important to consider when allocating resources and developing policies designed to support and nurture educational achievement.

We know too that making the decision to pursue higher education (51%); choosing a high quality college (57%); getting in to that college (57%) and achievement once you get there (46%) are also heritable, as indicated by the heritability estimates presented in parentheses (Smith-Woolley et al., 2018). For most of these university 'success' variables shared environmental factors explained little variance, suggesting that heritable characteristics and non-shared or random happenings drive these experiences. However, this was not the case for university enrolment where shared environmental factors explained almost half of the variance. Again, this indicates inequality of opportunity in that the decision to go to university appears to be influenced almost as much by family-wide factors as it is by individual characteristics such as ability, prior achievement and motivation. It is a good example of how genetic research can shine a light on areas of social injustice. Correcting for genetic effects adds a new nuance to important social policy questions and allows us to work towards a better understanding of environmental mechanisms. It suggests that more work is needed to promote the benefits of higher education to young people growing up in disadvantaged families.

A further point to note in making the case that 'everything is heritable' is that variables traditionally considered to be environmental, such as socio-economic status (SES), have also been found to be partly heritable, with approximately half of the variance in SES explained by DNA differences between individuals (Branigan, McCallum & Freese, 2013). This phenomenon is usually referred to as 'the nature of nurture' (Plomin & Bergeman, 1991). Therefore, in understanding how experience influences outcomes – particularly if the aim of that understanding is to maximise the positive impact of experience (e.g., school effects) – then it is vital to take the role of genes into account. If ‘everything is heritable’ then it seems unreasonable not to consider the implications of the heritability of behavior and experience in planning for the optimal deployment of education.

Nature via Nurture

We have described how heritability estimates only apply to a particular sample, place, and time and can be moderated by age and context. This makes clear that genes are rarely deterministic (single gene disorders such as Huntington’s disease being the exception) and that genotypes are dependent on the environmental circumstances in which an individual engages for behavioral expression. Policy-makers and school leaders have a vital role to play, therefore, in optimising the canteen of educational opportunities – the environmental circumstances – that each genotype, each child, will encounter. Genotype-environment interplay research clearly highlights this. If some children and young people find academic work more challenging and less engaging than others, partly for biological reasons, then it seems important to offer an education that can nurture their strengths and preferences as well as providing them with at least the minimum level of academic learning required to function effectively in society. If school rewards academic achievement above all else then it is bound to alienate some of those it exists to nurture, including the most vulnerable students.

Not controlling for the effect of genes in education or socialization research renders findings uninterpretable as it becomes impossible to ask whether a policy or practice works, or does not work, for truly environmental reasons. For example, taking Hart and Risley’s (1995) finding regarding the number of words heard by a young child and their vocabulary without considering whether vocabulary knowledge and use is transmitted genetically, environmentally – or both – led to outrage about a ’30 million word gap’ between poor children and their middle class counterparts and a raft of policies and charitable initiatives designed to teach economically poor parents how to speak to their children (Sperry, Sperry & Miller, 2019). Too much of developmental psychology makes the same assumption, that behavior is passed from parent to child environmentally, and behavioral genetic research undermines this assumption. Another good example relates to the recent popularity within education of psychological constructs such as grit (Duckworth & Quinn, 2009). Because most of the research on which grit is based is not genetically-informed, it is unclear whether the narrative surrounding it, and related constructs such as growth mindset, is valid (for additional critiques, see Crede, 2018; Sisk et al., 2018; Whitehurst, 2019). In fact research shows that grit is heritable (e.g., Lee & Wiggins, 2015; Rimfeld, Kovas, Dale & Plomin, 2016) and that it is almost indistinguishable from conscientiousness. Distinguishing grit from conscientiousness would, we argue, might be possible by incorporating passion into the scale – passion is a key element of the grit narrative but not of its measurement – and it would indeed be interesting to explore the heritability of how children and young people identify passions which they are motivated to persevere with in a genetically sensitive design, with clear implications for vocational education. However, whether the new passion scale is nonredundant from conscientiousness or other established constructs would still need to be carefully evaluated.

A focus on genotype-environment correlation (rge) is needed. There are three types of rge that were clearly laid out in a landmark paper over 40 years ago (Plomin et al., 1977). In a *passive rge* parents pass on their genes to their children but also create their environments, both of which feed into the child’s behavior. So, parents with a genetic predisposition to enjoy and be good at reading will pass on those genes to their children but will also curate an environment for their children that is likely to be ‘reading friendly’. This puts their children at an advantage compared to a family wherein the parents are genetically predisposed to find reading difficult, and therefore do not enjoy it, and who also create a home with fewer opportunities for reading development. The inequity here exists for both genetic and environmental reasons, which are clearly linked to each other. Not understanding passive genotype-environment correlation leads to policies with low chances of success such as buying books for disadvantaged families as a standalone policy. This sort of approach is likely to waste money and resources by not understanding that a lack of books is most likely driven by parent- and child-genotypes, rather than, simply, by economic circumstances. The two other types of rge to consider are *evocative rge* (in which people respond to a child on the basis of his or her inherited characteristics) and *active rge* (in which a child seeks out certain experiences - libraries, sports teams, friendship groups etc.) on the basis of their inherited characteristics (Scarr & McCartney, 1983). In all of these instances, genotypes drive experiences and a clear understanding of the possible implications of this raises challenges for education policy-making and resourcing decisions.

The other major type of genotype-environment interplay has a moderating (rather than a mediating) effect and is known as Genotype (or Gene) x Environment Interaction (GxE). The study described earlier, in which the heritability of reading among Florida school children was higher for those taught by higher quality teachers is an example of GxE. Another illustrative example was reported by Turkheimer and colleagues (2003) who found the heritability of cognitive ability to be significantly lower for children in disadvantaged families compared to those in affluent families. For children in disadvantaged families, shared environmental factors explained around 60% of individual differences in U.S. seven-year-olds, with DNA differences explaining almost no variance, while this pattern was reversed in children from wealthier families. This is a highly cited finding but perhaps the most interesting element is that the pattern does not replicate elsewhere in the world (Tucker-Drob & Bates, 2016). The suppression of heritability in disadvantaged environments appears to be a U.S. phenomenon (although not all U.S. based studies have supported it: e.g., Figlio et al., 2017). This raises interesting questions about the U.S. system of education and about why the heritability of cognitive ability for children from poor families might be reduced in the U.S. but not elsewhere. One likely explanation is the greater diversity of educational input in the U.S. than in Europe and Australia where National Curricula are commonplace. In countries with a National Curriculum every child has access to approximately the same education, and is tested on the same material, regardless of their geographical location or economic circumstances. This removes variance that could be explained by curriculum-related inequalities, leaving relative achievement to be better explained by individual characteristics. This has led some to suggest that heritability could be viewed as an index of equality (e.g., Plomin, 2018). This counter-intuitive idea is based on an understanding that if students have genuinely equal environments, then environmental factors will not be able to explain individual differences (because they will not differ between individuals). We might expect that individual differences would be reduced (as environmental inequality was eliminated) and therefore any remaining variation (which would still be substantial) would be explained by genetic factors and chance events. In an equal society everybody would have the opportunity to fully access environments that supported their personal needs, abilities and preferences and we would be left with behavioral differences primarily explained by DNA differences. While the idea of genetic inequality is not necessarily much less problematic than the idea of a society built on social inequities and injustices, it is an argument that has an important place in any debate about equality and social justice in education.

Some U.S. education policy scholars have suggested that a more uniform knowledge-based curriculum would be beneficial for all students (e.g., Hirsch, 1988; Pondiscio, 2019).

We note here that, to the extent to which the curriculum is made more uniform – whether Hirschian or not – we would expect it to lead to an increase in heritability because it would remove some of the environmental variance (curriculum differences between teachers and between schools) and ensure that all children had access to the same content. This could have implications for curricular and finance reform, among other areas of education policy.

In sum then, over a half century of broadly replicated evidence from the field of behavioral genetics has made clear that accepting the importance of genetic influences on educational outcomes, and working to better understand the interface between genes and experiences, should have a profound impact on policy discussions and should lead to a focus on individual differences as well as a focus on averages (Martschenko, Trejo, & Domingue, 2019). A case can be made that not doing so poses a threat to the likelihood of identifying the types of educational opportunities that can help students most.

Polygenic Risk Scores and the speed of Science

Until recent years behavioral genetics was often criticized for its 'missing heritability problem' (e.g., Maher, 2008; Plomin, 2013). This problem referred to the fact that while twin and adoption studies had identified moderate to substantial heritability estimates for a diverse array of behavioral traits, very few actual genetic variants had been found to explain or justify the heritability estimates. In the last few years, however, we have witnessed what has been termed a 'DNA Revolution' (Plomin, 2018). As one failed attempt to find genes associated with behavior followed another it became increasingly clear to the genetics community that behavior was likely to be explained by many genetic variants of individually miniscule effect. The main challenge associated with identifying alleles with vanishingly small effects was one of statistical power. Thus began the push to combine samples from around the world in order to find the relevant genes. In 2016 the Social Science Genetic Association Consortium conducted a genome-wide association study (GWAS) with an international sample of almost 300,000 participants in an attempt to find specific genetic variants associated with years of education (Okbay et al., 2016). They found 74 such variants, which they combined into a polygenic score known as EduYears. Their achievement represented a major step forward as a previous attempt with a sample of just over 100,000 participants had only identified three such genetic variants, all of which replicated in this new study (Rietveld et al., 2013) and suggested that the notion that all that was stopping scientists from identifying educationally-relevant genetic variants was sample size and statistical power was correct. Because of the small individual contribution such variants make it is sensible to combine them in polygenic scores with the potential for meaningful prediction. This was an enormous success story. However, EduYears was only able to explain approximately 4% of the variance in years of education. Policy-makers can be forgiven for not getting particularly excited about this, especially given the unsophisticated nature of the outcome variable. This was very clearly work in progress. However, this progress has continued apace and it is now time to take notice. In summer 2018 the third version of this polygenic score, known as EA3, was generated on the basis of data from 1.1 million participants and is made up of over 1000 individual genetic variants (Lee et al., 2018). EA3 explains 11-13% of individual differences in years of school, and 7-10% of individual differences in cognitive ability. One U.K. study found that EA3 predicted 14% of the variance in educational achievement at age 16 (von Stumm et al., 2019). At the same stage SES explained 23% of the variance but, after controlling for genetic influences on SES it explained 16% of individual differences in academic performance. EA3 can therefore be considered as being roughly equivalent to SES as a driver of individual differences in academic performance. We also know that EA3 becomes increasingly powerful as a predictor over time, as suggested by earlier research on the increasing heritability of cognitive ability over time (Allegrini et al., 2018). The explanatory power of polygenic scores, at the population level, has become meaningful and poses questions for education which need to be rigorously and sensitively explored. EA3 explains as much variance as some measures of family income and this raises the question of whether a low EA3 score can be considered as an indicator of disadvantage in the same way as low family income and, if so, what can and should be done about that?

Implications for policy and practice

It is important to reiterate that, although this body of research is highly robust and replicated, no necessary policy implications follow from it and, indeed, it raises more questions than solutions at this point. The questions it raises are important and merit widespread discussion, as well as the re-reading – and perhaps attempt at replication – of some educational research using a 'genetic lens'. Policy solutions within European countries may be different than in the U.S. which may have different debates and concerns (e.g., Henderson et al., 2019). This may, or may not, lead to new ways of doing things, but should at least inform the body of evidence used in decision making. Our aim in this paper has been to introduce key illustrative studies and to make a case that education policies and practices, along with educational research, can be informed by this research. In this concluding section we briefly outline some of the areas of policy, and discussions, that behavioral genetic research could potentially make a meaningful contribution to. These are speculative and policy-makers and educational policy researchers may well identify other areas where the 'genetic lens' has more to offer. We focus on two sets of possible implications that exemplify how this might work. The first is rooted in Scarr & McCartney's (1983) Theory of Genotype → Environment Effects and has implications for policies related to supporting individual differences via student choice, and providing equal opportunities to all. The second concerns how we define disadvantage and the policies that flow from this.

If genotypes drive experiences then, in a perfectly equal world, everything should be close to 100% heritable. This is not the case for many reasons. One of these reasons is that non-shared environmental factors (idiosyncratic, or chance, experiences that are uncorrelated with genetic effects and include measurement error) explain some variance and will continue to do so even in the most equal of societies. Scarr and McCartney (1983) explain how, outside of these more random occurrences, genes drive experiences. However, if a child has the genetic propensity to become a jockey but grows up in a home without access to horses this is unlikely to happen. Equally, if a child has a propensity to thrive in higher education but grows up in a home – or is educated in a school – where this is not the expectation for a 'child like him' then his genotype may be denied the opportunity to drive his experience (making space for shared environmental effects, as noted above). Policy-makers are in a position to support the process of genotype-environment correlation by ensuring that all children have an equally diverse canteen of developmental opportunities to choose from. Alongside the provision of such opportunities it is clear that barriers to accessing them – which could include finances, transportation, disability and home circumstances – will need to be addressed. One aspect of U.S. education policy this may be linked to is the discussion over school choice (e.g., Diperna, 2019; Wolf, 2018).

The literature on behavioral genetics is largely focused on asking "reverse causal questions" rather than questions about "forward causal inference" (Wai & Bailey, in press). Reverse causal questions are those about the unknown causes of known effects. Forward causal inference—the approach typically taken by many education policy researchers—focuses on estimating the unknown effects of known causes (Gelman & Imbens, 2013). We note that there is a broad literature—spanning psychological individual differences to education policy—suggesting that the vast majority of student achievement outcomes are due to student traits or characteristics (see Detterman, 2016, for a review), which are heritable, whereas a much smaller portion of student achievement variance is due to teachers or schools (e.g., Gibbons & Silva, 2011; Whitehurst, Chingos, & Gallaher, 2013), in particular within genetically sensitive designs (Grasby et al., 2019). We clarify that although more discussion in education policy should surround the fact that most of student achievement and long-term outcome variance is due to student characteristics, there is also a large body of rigorous research by many policy researchers focusing on estimating the unknown effects of known causes, including in the area of school choice (e.g., Wolf, 2019), and that these two approaches are complimentary (Wai & Bailey, in press).

In terms of how we define and respond to disadvantage it is worth considering whether, in a world in which a polygenic score for educational attainment has as much predictive power as some measures of family income, we need to consider cognitive and genetic indices of disadvantage as well as social and economic ones. We argue that it is important to consider whether policies designed to compensate for disadvantage should also take such indices into account, and what the practical and ethical implications of doing so would be. This would require better understanding how people might see as the risks and benefits of using this information.

We fully understand many of those involved in education policy are eager to find solutions to implement and evaluate, and we have sought to provide tentative suggestions for the ways in which this information we reviewed here might provide a new way of looking at policy discussions and evidence. However, we note that psychologists (and even more so geneticists) are rightly cautious about ensuring there is a large amount of replicable evidence prior to importing findings into an applied area such as education policy. The evidence from the field of behavioral genetics is one of the most robust literatures that has amassed across the last half century (Polderman et al., 2015). And yet, we still urge caution in applying these findings to education policy contexts. In that sense, we also urge education policymakers to more deeply consider the strength of evidence surrounding psychological or other constructs prior to importing them into far-reaching interventions, and to update their expectations for efficacy based on the ongoing updating of the psychological and behavioral genetic research literature (e.g., Open Science Collaboration, 2015).

Conclusions

In conclusion we argue that there is strong reason to believe that education policy and practice can be enhanced by including evidence from behavioral genetics and individual differences. While no necessary policy implications follow from the evidence, the large research base supporting the ‘genetic lens’ offers policy-makers an opportunity to take a new, evidence-based perspective on why some specific policies have worked whereas others have not, and to inform broader discussions of equality, fairness and disadvantage in education.

References

Allegrini, A., Selzam, S., Rimfeld, K., von Stumm, S., Pingault, J. B., & Plomin, R. (2018). Genomic prediction of cognitive traits in childhood and adolescence. *bioRxiv*, 418210.

Branigan, A. R., McCallum, K. J., & Freese, J. (2013). Variation in the heritability of educational attainment: An international meta-analysis. *Social forces*, *92*, 109-140.

de Zeeuw, E. L., de Geus, E. J., & Boomsma, D. I. (2015). Meta-analysis of twin studies highlights the importance of genetic variation in primary school educational achievement. *Trends in Neuroscience and Education*, *4*, 69-76.

Crede, M. (2018). What shall we do about grit? A critical review of what we know and we don't know. *Educational Researcher, 47,* 606-611.

Detterman, D. K. (2016). Pity the poor teacher because student characteristics are more significant than teachers or schools. *Spanish Journal of Psychology, 19*, E93.

Diperna, P. (2019). 2019 schooling in America survey. *Ed Choice*. Retrieved from: https://www.edchoice.org/research/2019-schooling-in-america-survey/

Duckworth, A. L., & Quinn, P. D. (2009). Development and validation of the Short Grit Scale (GRIT–S). *Journal of personality assessment*, *91*(2), 166-174.

Figlio, D. N., Freese, J., Karbownik, K., & Roth, J. (2017). Socioeconomic status and genetic influences on cognitive development. *Proceedings of the National Academy of Sciences*, *114*, 13441-13446.

Gelman, A., & Imbens, G. (2013). Why ask why? Forward causal inference and reverse causal questions. *NBER Working Paper 19614:* https://www.nber.org/papers/w19614

Gibbons, S., & Silva, O. (2011). School quality, child wellbeing and parents' satisfaction. *Economics of Education Review, 30,* 312-331.

Grasby, K. L., Little, C. W., Byrne, B., Coventry, W. L., Olson, R. K., & Larsen, S. (2019). Estimating classroom-level influences on literacy and numeracy: A twin study. *Journal of Educational Psychology*. Advance online publication.

Hart, S. A., Little, C., & van Bergen, E. (2019). Nurture might be nature: Cautionary tales and proposed solutions. *PsArXiv Preprint*. Retrieved from: https://psyarxiv.com/j5x7g/

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Paul H Brookes Publishing.

Haworth, C. M., Wright, M. J., Luciano, M., Martin, N. G., de Geus, E. J., van Beijsterveldt, C. E., ... & Kovas, Y. (2010). The heritability of general cognitive ability increases linearly from childhood to young adulthood. *Molecular psychiatry*, *15*(, 1112 - 1120.

Henderson, M. B., Houston, D., Peterson, P. E., & West, M. R. (2019). Public support grows for higher teacher pay and expanded school choice. *Education Next, 20*. Retrieved from: https://www.educationnext.org/school-choice-trump-era-results-2019-education-next-poll/

Hirsch, E. D. (1988). *Cultural literacy: What every American needs to know*. New York, NY: Vintage.

Knopik, V. S., Neiderhiser, J. M., DeFries, J. C., & Plomin, R. (2016). *Behavioral genetics*. Macmillan Higher Education.

Kovas, Y., Haworth, C. M., Dale, P. S., & Plomin, R. (2007). The genetic and environmental origins of learning abilities and disabilities in the early school years. *Monographs of the Society for research in Child Development*, *72*, vii-1.

Kovas, Y., Voronin, I., Kaydalov, A., Malykh, S. B., Dale, P. S., & Plomin, R. (2013). Literacy and numeracy are more heritable than intelligence in primary school. *Psychological science*, *24*, 2048-2056.

Krapohl, E., Rimfeld, K., Shakeshaft, N. G., Trzaskowski, M., McMillan, A., Pingault, J. B., ... & Plomin, R. (2014). The high heritability of educational achievement reflects many genetically influenced traits, not just intelligence. *Proceedings of the National Academy of Sciences*, *111*, 15273-15278.

Lee, J. J., Wedow, R., Okbay, A., Kong, E., Maghzian, O., Zacher, M., ... & Fontana, M. A. (2018). Gene discovery and polygenic prediction from a genome-wide association study of educational attainment in 1.1 million individuals. *Nature genetics*, *50*, 1112.

Lee, J., & Wiggins, K. (2015). Growth mindset theory is ‘overplayed’ and could be harmful, geneticist warns. *Times Educational Supplement*. Retrieved from: https://www.tes.com/news/growth-mindset-theory-overplayed-and-could-be-harmful-geneticist-warns

Little, C. W., Haughbrook, R., & Hart, S. A. (2017). Cross-study differences in the etiology of reading comprehension: A meta-analytical review of twin studies. *Behavior genetics*, *47*, 52-76.

Maher, B. (2008). Personal genomes: The case of the missing heritability. *Nature News*, *456*, 18-21.

Martschenko, D., Trejo, S., & Domingue, B. W. (2019). Genetics and Education: Recent developments in the context of an ugly history and an uncertain future. *AERA Open*, *5*, 2332858418810516.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science, 349,* aac4716.

Okbay, A., Beauchamp, J. P., Fontana, M. A., Lee, J. J., Pers, T. H., Rietveld, C. A., ... & Oskarsson, S. (2016). Genome-wide association study identifies 74 loci associated with educational attainment. *Nature*, *533*, 539.

Plomin, R. (2013). Commentary: Missing heritability, polygenic scores, and gene–environment correlation. *Journal of Child Psychology and Psychiatry*, *54*, 1147-1149.

Plomin, R. (2018). *Blueprint: How DNA makes us who we are*. MIT Press.

Plomin, R., & Bergeman, C. S. (1991). The nature of nurture: Genetic influence on “environmental” measures. *Behavioral and Brain Sciences*, *14*, 373-386.

Plomin, R., & Deary, I. J. (2015). Genetics and intelligence differences: five special findings. *Molecular psychiatry*, *20*, 98 - 108.

Plomin, R., DeFries, J. C., & Loehlin, J. C. (1977). Genotype-environment interaction and correlation in the analysis of human behavior. *Psychological bulletin*, *84*, 309 - 322.

Plomin, R., Owen, M. J., & McGuffin, P. (1994). The genetic basis of complex human behaviors. *Science*, *264*, 1733-1739.

Polderman, T. J., Benyamin, B., De Leeuw, C. A., Sullivan, P. F., Van Bochoven, A., Visscher, P. M., & Posthuma, D. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. *Nature genetics*, *47*, 702-709.

Pondiscio, R. (2019). *How the other half learns: Equality, excellence, and the battle over school choice*. New York, NY: Avery.

Rietveld, C. A., Medland, S. E., Derringer, J., Yang, J., Esko, T., Martin, N. W., ... & Albrecht, E. (2013). GWAS of 126,559 individuals identifies genetic variants associated with educational attainment. *science*, *340*, 1467-1471.

Rimfeld, K., Ayorech, Z., Dale, P. S., Kovas, Y., & Plomin, R. (2016). Genetics affects choice of academic subjects as well as achievement. *Scientific reports*, *6*, 26373.

Rimfield, K., Kovas, Y., Dale, P. S., & Plomin, R. (2016). True grit and genetics: Predicting academic achievement from personality. *Journal of Personality and Social Psychology, 111,* 780-789.

Ritchie, S. J., & Tucker-Drob, E. M. (2018). How much does education improve intelligence? A meta-analysis. *Psychological science*, *29*, 1358-1369.

Samuelsson, S., Byrne, B., Olson, R. K., Hulslander, J., Wadsworth, S., Corley, R., ... & DeFries, J. C. (2008). Response to early literacy instruction in the United States, Australia, and Scandinavia: A behavioral-genetic analysis. *Learning and individual differences*, *18*, 289-295.

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype→ environment effects. *Child development, 54*, 424-435.

Shakeshaft, N. G., Trzaskowski, M., McMillan, A., Rimfeld, K., Krapohl, E., Haworth, C. M., ... & Plomin, R. (2013). Strong genetic influence on a UK nationwide test of educational achievement at the end of compulsory education at age 16. *PloS one*, *8*, e80341.

Sisk, V. F., Burgoyne, A. P., Sun, J., Butler, J. L., & Macnamara, B. N. (2018). To what extent and under which circumstances are growth mindsets important to academic achievement? Two meta-analyses. *Psychological Science, 29,* 549-571.

Smith-Woolley, E., Ayorech, Z., Dale, P. S., von Stumm, S., & Plomin, R. (2018). The genetics of university success. *Scientific reports*, *8*, 14579.

Sperry, D. E., Sperry, L. L., & Miller, P. J. (2019). Reexamining the verbal environments of children from different socioeconomic backgrounds. *Child development*, *90*, 1303-1318.

Taylor, J., Roehrig, A. D., Hensler, B. S., Connor, C. M., & Schatschneider, C. (2010). Teacher quality moderates the genetic effects on early reading. *Science*, *328*, 512-514.

Tucker-Drob, E. M., & Bates, T. C. (2016). Large cross-national differences in gene× socioeconomic status interaction on intelligence. *Psychological Science*, *27*, 138-149.

Turkheimer, E., & Gottesman, I. I. (1991). Is H 2= 0 a null hypothesis anymore?. *Behavioral and Brain Sciences*, *14*, 410-411.

Turkheimer, E., Haley, A., Waldron, M., d'Onofrio, B., & Gottesman, I. I. (2003). Socioeconomic status modifies heritability of IQ in young children. *Psychological science*, *14*, 623-628.

von Stumm, S., Smith-Woolley, E., Ayorech, Z., McMillan, A., Rimfeld, K., Dale, P., & Plomin, R. (2019). Predicting educational achievement from genomic measures and socioeconomic status. *bioRxiv*, 538108.

Wai, J., & Bailey, D. (in press). How intelligence research can inform education and public policy. To be published in A. K. Barbey, S. Karama, & R. J. Haier (Eds), *The Cambridge Handbook of Intelligence and Cognitive Neuroscience*. Retrieved from: https://www.researchgate.net/publication/335798156_How_Intelligence_Research_Can_Inform_Education_and_Public_Policy

Whitehurst, G. J. (2019). A prevalence of "policy-based evidence-making". *Education Next, 19*. Retrieved from: https://www.educationnext.org/prevalence-policy-based-evidence-making-forum-should-schools-embrace-social-emotional-learning/

Whitehurst, G. J., Chingos, M. M., & Gallaher, M. R. (2013). Do school districts matter? *Brookings Institution*. Retreived from: https://www.brookings.edu/research/do-school-districts-matter/

Wolf, P. (Ed.) (2019). *School choice: Separating fact from fiction*. New York, NY: Routledge.