Should we teach about the genetics of inheritance?

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Abstract School genetics is changing. Nowadays, students are more likely to be introduced to the idea that many characteristics of organisms, including those of humans, are not determined by the actions of just one or two genes but result from interactions between the products of many genes and the environments of each organism. This article asks whether there is a place in school science for teaching about the genetics of inheritance. There are arguments in favour of such teaching but also risks.

This article asks whether there is a place in school science for teaching about the genetics of inheritance. Biologists have known since the publication of Charles Darwin's *On the Origin of Species by Means of Natural Selection* that inherited variation plays an important role in the various characteristics exhibited by living organisms. Darwin argued that this applies to behaviours as well as to structures and he reasoned that features such as intelligence had also evolved over time as a result of the benefits they had for individuals. The question then arises whether we should teach about the inheritance of intelligence in schools.

The relevance of school genetics

One of the common complaints from many students when faced with their teaching is to claim that it isn't 'relevant'. To most teachers of secondary level biology, there are few topics that could be of more relevance than genetics. Genetics is at the heart of who we are and how we come across to others. Genetics explains how the theory of evolution through natural selection works and it is central to such applied topics as plant breeding and biotechnology. Nevertheless, school students fed on a diet of Mendel's peas and the inheritance of eye colour may not see it that way.

Recently, there have been calls for school genetics to change substantially. In one major study, which ran from 2012 to 2015, an international group of 57 experts, involved in teaching, studying or developing genetics education and communication or working with genetic applications in medicine, agriculture or forensics, attempted to answer the questions: '*What knowledge of genetics is relevant to those individuals not professionally involved in science?*' and '*Why is this knowledge relevant?*' (Boerwinkel, Yarden and Waarlo, 2017). As the authors of this study point out:

> *Results from studies in genetics influence societal practices… It has also become clear that many genes interact to produce phenotypes, that gene expression is modulated by the environment, and that the path from gene to trait is more complex than previously thought. Thus, images of genes and genomes have changed fundamentally … Nevertheless, few of these developments are addressed in biology education: The gap between scientific understanding of genetics and what is taught in genetic education in schools has increased.* (Boerwinkel *et al*., 2017: 1087–1088)

So, if we accept that the gap between scientific understanding of genetics and what is taught in genetics education in schools has increased, is there a place for teaching about the genetics of intelligence? One of my arguments is that there is a surprising disconnect between what most academics in education and what many academics in biology think about the role of genetic inheritance in many areas of human life, including how well children do in schools (Reiss, 2018). Here, I want to look at why there is this disconnect and then examine the core issue of the role of genetic inheritance in school performance. I make three claims:

1. Education needs to stop ignoring the possible role of genetic inheritance in school performance.
2. Genetic inheritance can play a significant role in how well children perform and achieve in schools.
3. This does not mean that children's school performance is predetermined, that is, fixed in advance.

Education needs to stop ignoring the possible role of genetics in school performance

Since Darwin, biologists have accepted that inherited variation plays a central role in the manifestation of the characteristics exhibited by organisms. This acceptance was only enhanced by the early 20th century advances in genetics, followed by the mid-20th century advances of neo-Darwinism and subsequent developments in molecular biology.

As far as our own species goes, this means that just about everything of interest about humans has an inherited component. It doesn't matter whether we are talking about height or body mass or personality or our susceptibility to various diseases or anything else, inheritance generally plays a role. Furthermore, this is also the case for such educationally significant factors as general intelligence, reading ability and examination success.

Many people – including parents and teachers – are happy to accept that children differ greatly in their abilities or potential (e.g. at music, mathematics or sports). However, educators are generally reluctant (e.g. White, 2006) to accept the mounting weight of evidence for the importance of genetic inheritance in school performance. I think that there are a number of reasons for this reluctance – all well intentioned.

First of all, there have been times when genetics has led to major injustices. Various historians of science (e.g. Gould, 1981; Lewontin, 1991) have long since shown how genetics has been used, both consciously and unconsciously, to argue for the inferiority of women, of black and other minority ethnic people and of those not in the upper or middle classes. Faced with this legacy of sexism, racism and general condescension, it is not surprising that educators, who are generally, in my experience, in favour of equity, have rejected genetics as a way of understanding what is important about human nature. As a result, I think that what has happened is that *much of human genetics*, rather than the *misuse of human genetics*, has been rejected. It is as if outdoor activities in general were banned because some outdoor activities are dangerous. The reality, though, is that a *better* understanding of human genetics, not the *abandonment* of human genetics, is what is needed. This is where school science, I believe, has a role to play.

A second reason for the widespread scepticism among educators, certainly in the UK, concerning the importance of inheritance in educational attainment is because of the legacy of Cyril Burt. Burt (1883–1971) was an educational psychologist who played an important role in the development of an examination that survives to this day: the '11-plus'. In England, this optional examination is taken in some parts of the country at age 11 to determine whether students are then educated in selective grammar schools or less academically demanding schools (typically, secondary moderns). Although Burt has his defenders (e.g. Tredoux, 2015), it is generally thought that he systematically engaged in scientific fraud, falsely claiming to have collected data in his studies on the heritability of intelligence (Tucker, 1997). However, the findings that he 'produced' on the extent to which intelligence is inherited were in line with other studies. In other words, even if we ignore Burt's work, there would be no effect on the conclusions to be reached from the early literature about the role of inheritance in the determination of intelligence.

A third reason why educators have tended to ignore the ever-increasing growth in what is known about the inheritance of intelligence is, I think, because of a widespread, often implicit, presumption that *inheritance* is to be equated with *determinism*, a very widespread misunderstanding. I shall address this misunderstanding below; first I turn to the central issue – namely the role that inheritance plays in school performance.

Inheritance plays a role in how well children do in schools

Geneticists determine the extent to which inheritance plays a role in the determination of characteristics in much the same way, whether we are considering the colour of plant seeds, the wool yield of sheep or the mathematical performance of children. Throughout, of course, by 'inheritance' I mean 'genetic inheritance'. Everyone accepts that, for example, family background is important in much that is of interest about us. If one is brought up in a home with lots of books and where reading is valued, it is hardly surprising that one is likely to do better at reading as a child than another child of the same age who has not enjoyed such benefits. I remember as a child, aged about seven, having missed a couple of weeks of school for some routine childhood infectious disease. When I returned, my kind teacher – and I can still recall the concerned expression on her face – said that the class had started on multiplication. '*That's quite alright*,' I reassured her, '*my mother has shown me how to do that*.' Much of the skill in arriving at measures of 'heritability' – the extent to which genetics plays a role – is precisely to do with disentangling, in so far as one can, the complicated and intertwined effects of the environment and the genes.

There are a number of ways in which the importance of the genes in the manifestation of characteristics can be determined. A standard set of practices is as follows:

1. Determine how to measure the characteristic in question.
2. Collect such data from a large number (ideally many thousands) of individuals.
3. Get a measure of the extent to which these individuals have similar genetic constitutions.
4. Get a measure of the extent to which these individuals have similar environmental backgrounds.

The first of these is fairly easy for things like crop yields but harder (in the sense that the measure may not be as robust) for most things of educational interest, such as reading ability or performance in examinations. In particular, there has been a long history of researchers making overconfident measurements of intelligence (Figure 1) that turn out to tell us rather more about the assumptions of the researchers and the cultural similarities between them and their research subjects than about the research subjects' intelligence.

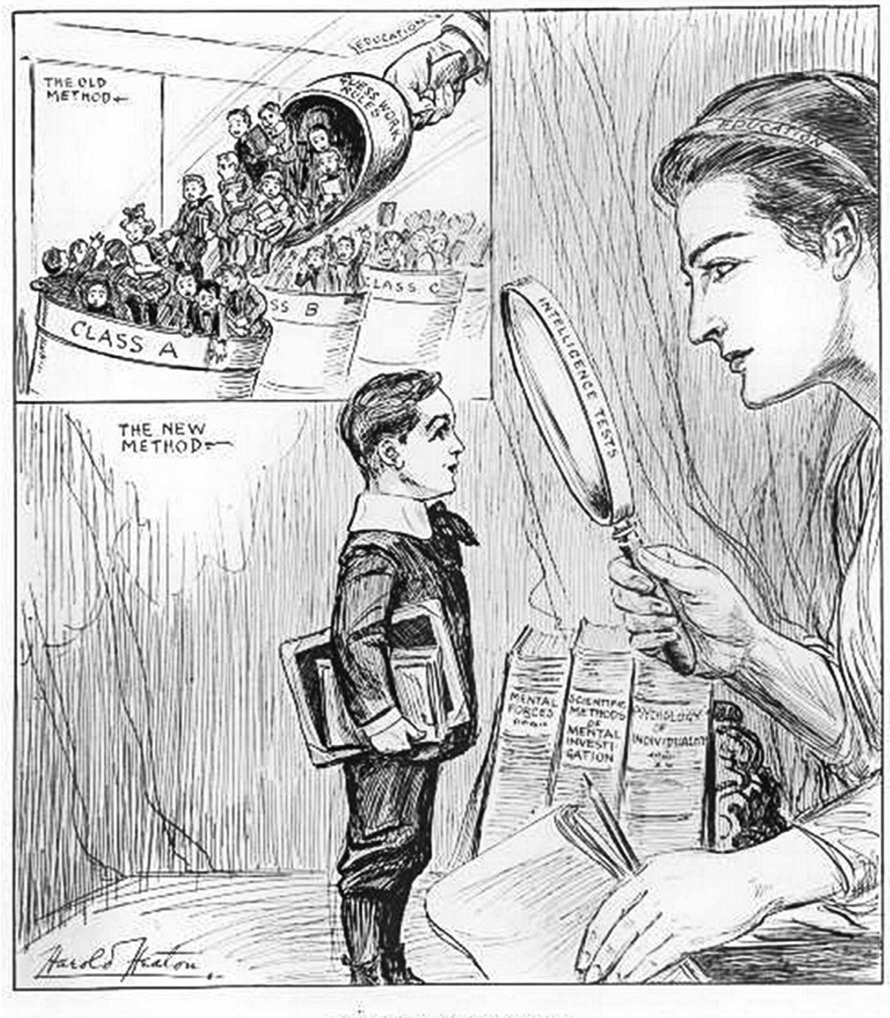
The second requirement in the above list is straightforward, if a bit time-consuming, whether we are talking about crops, farm animals or humans. It's the third and fourth ones that are the most difficult to do, and for this reason a number of human studies have relied on studies on twins (Figure 2). Twin studies are of particular value because there are two sorts of twins – identical twins and non-identical twins. Non-identical twins are no more genetically similar than are any two non-twin siblings but, because they have been born from the same pregnancy, they have shared an early environment that is more similar than that shared by non-twin siblings. Identical twins have an early environment that is at least as similar as that shared by non-identical twins (the caveat 'at least' is needed as there are various types of identical twins depending on how soon after fertilisation the fertilised zygote divided into two); in addition, they are virtually identical genetically. As a result, by looking at the extent to which monozygotic (identical) twins are more similar in certain characteristics than are dizygotic (non-identical) twins, a measure can be made of the heritability of the characteristics in question.

To give a rather clear-cut example: identical twins typically have very similar eye colour – more similar than is the case for non-identical twins. We therefore conclude that eye colour has a high heritability. However, identical twins are not more similar than are non-identical twins in respect of the language (e.g. English, Turkish) that they speak best. This is simply the result of the first language of the family in which a child grows up – whether the child is an identical twin or not and whether the child grows up in its biological family or not. We therefore conclude that the language one speaks best has a very low heritability.

There are various ways nowadays of calculating heritabilities and they give similar values – which is encouraging from a scientific point of view. Heritabilities can lie between close to 0 (e.g. the language one speaks best) and close to 1 (e.g. eye colour). Virtually all human behaviours tend to have heritabilities of about 0.3 to 0.6 (Bouchard, 2004). This means that human behaviours are moderately heritable – not as heritable as height (with a heritability in the West of about 0.9) but more so than religiosity (which has a heritability of about 0.1 to 0.2). Examples of human 'behaviours' are such things as personality, intelligence, artistic interests and the chances of developing a psychiatric illness.

With regard to school performance, a thorough summary of the argument that human genetics plays an important role is provided by Asbury and Plomin's (2014) *G is for Genes: The Impact of Genetics on Education and Achievement* and Plomin's (2018) *Blueprint: How DNA Makes Us Who We Are*. Robert Plomin is one of the long-running advocates of the view that genetics plays a central role in our characteristics. He set up the Twins Early Development Study (TEDS) in 1994 when he moved to the UK from the USA. TEDS is now one of the largest and longest-running twin studies in the world with about 13 000 pairs of twins.

Twin studies have historically been of great value in inheritance studies as they do not require the sort of DNA mapping that has only fairly recently become widely (and affordably) available. Nowadays, other



The Pupil Becomes an Individual

Figure 1 Intelligence testing for use in schools has sometimes promised more than it can deliver (from the cover of the April 1922 issue of the *American School Board Journal*)

Figure 2 Studies on twins have contributed greatly to what is known about the inheritance of characteristics in humans; this photograph shows the 8th Iranian Twins and Multiples Festival, 11 May 2018; image from Fars News Agency, reproduced under a Creative Commons Attribution 4.0 International license

approaches in addition to twin studies are becoming of increasing value in determining human heritabilities. The exceptionally rapid decrease in the cost of DNA sequencing means that it is becoming possible to screen large numbers of people (through genome-wide association studies) to see if they have particular gene sequences that are of interest with regards to particular characteristics. Because they involve large numbers of people (typically in the tens of thousands), genome-wide association studies are good at identifying genes and combinations of genes that have only small effects on the characteristic(s) in question – an important point as it means that one can nowadays find genes that contribute to just about any human characteristics, even if it turns out that the contribution of a particular gene is miniscule and the collective contribution of all the genes examined is very small.

Nevertheless, despite this caveat, it is clear that it is no longer possible validly to conclude that genetics plays no part in the determination of educational success. For example, in the UK, there is a non-trivial genetic component to university examination success (Smith-Woolley *et al.*, 2018). Furthermore, it is not just intelligence and examination performance that are heritable; for instance, genetic factors are implicated in mathematical anxiety (Wang *et al.*, 2014).

There is more to this than genes

Calculating heritabilities and stating that differences between genes are involved in characteristics such as intelligence does not mean that genes alone are important. For a start, there is the obvious truth that genes need the rest of cells to work – on their own, genes can do nothing. Then there is the fact that we could as well talk about the roles that proteins (and other gene products) play in intelligence. The key reason we usually talk about genes is because it is genes that are inherited. For example, changes to protein structure that are not the result of changes to DNA structure are not passed on to the next generation.

Even those who argue strongly for the importance of genetics in the development of human characteristics acknowledge that sometimes genetics plays less of a role than is commonly supposed. Plomin points out that whereas people typically presume that breast cancer is strongly influenced by genetics, in fact it has a heritability of only about 10% (Plomin, 2018) – which may help reassure you if you have a family member who has breast cancer. It is interesting that, despite this low heritability, when one looks at health websites on the causes of breast cancer (e.g. www.nhs.uk/conditions/breast-cancer/causes), having pointed out that being female and older are key correlates, having a close relative who has or has had breast cancer tends to feature strongly. The reality is that there seem to be multiple causes of breast cancer, some of which are still poorly understood.

In respect of intelligence, another reason to appreciate the importance of non-genetic influences is the Flynn effect (2016). Throughout the 20th century, there were large increases in IQ (intelligence quotient) scores over time in just about every country where such data were collected. Each decade, average IQ scores increased by about 2.5–3 points (IQ tests are designed so that at some point in time the average outcome is 100 points). Over the 20th century this increase amounts to 25–30 points, almost 2 standard deviations. A number of factors are believed to contribute – including better health, better education and better nutrition – but the important point is that such data indicate the extent to which intelligence has an important environmental component.

Some of the strongest criticisms of the argument that genes are important determinants of educational success have come from the veteran biologist, Steven Rose. One of Rose's key points is that calculations of heritability depend on the environment – this is well known but easy to forget. A classic example is that human height shows higher heritability in high-income countries than in low-income ones where poor nutrition and disease play a greater role (Perkins *et al.*, 2016). In the same way, Turkheimer *et al.* (2003) concluded that '*in impoverished families, 60% of the variance in IQ is accounted for by the shared environment, and the contribution of genes is close to zero; in affluent families, the result is almost exactly the reverse*' (p. 623). Another point Rose and others make is that gene–environment interactions (possibly of particular significance in human characteristics such as learning) make it even more difficult (less meaningful) to partition out effects between genes and the environment (Rose, 2014).

Nevertheless, and as argued above, there is virtually no doubt that there is a genetic component to intelligence. However, the contribution of any one gene locus is almost always extremely small. Even large numbers of genes considered together typically account for only a relatively small percentage of the observed variation. For example, a recent large study undertaken on over one million individuals identified 1271 independent genome-wide-significant SNPs (single nucleotide polymorphisms) (Lee *et al.*, 2018). However, collectively these only accounted for 11–13% of the variance in educational attainment and 7–10% of the variance in cognitive performance.

Should we teach about the genetics of intelligence?

There is an important risk in teaching about the genetics of intelligence. Because of the common, though mistaken, equation of genetics with destiny (the belief that genes are entirely determinative), students may mistakenly come to think that there is little that can be done to counteract the effect of genes. There is a widespread misconception that one's genes determine one's characteristics. This misconception is probably partly the result of how school biology often teaches classical Mendelian genetics. Introducing students to the simplest cases of inheritance – such as that involved in the characteristics of pea plants, human eye colour, and diseases like sickle cell anaemia and cystic fibrosis – can give the impression that all inheritance is like this. Teaching students more complicated, but more typical, examples of inheritance can help correct this misconception (Gericke and El-Hani, 2018).

Teaching about the genetics of intelligence might provide a good opportunity to teach students about the growth mindset approach. The key argument here is that if learners believe that they can improve their performance (intelligence, subject attainment, skills, examination success or whatever), they will do better than if they believe that their performance is predetermined and cannot substantially be improved (Dweck, 2017). This does not, of course, mean that any of us can achieve whatever we want simply by trying hard – another educational myth that is in its own way as unhelpful as the one that asserts that we differ innately and unalterably in our abilities. As most teachers and parents know, the reality lies somewhere in between, and often in unpredictable ways. Some children really do show a natural aptitude for music, mathematics, ball sports or whatever. But all of us can improve. I may never develop the mathematical abilities of an Einstein or the sporting prowess of Martina Navratilova, but we are who we are as a result of a complicated and lifelong series of interactions between our DNA and our various environments – environments that start from the moment of conception and continue throughout our lives; environments that we partly form as a result of our interests and circumstances.

Furthermore, and especially in relation to intelligence, there isn't a single 'thing' called 'intelligence'. When I was a teenager, I remember taking a number of those intelligence tests one can nowadays find online but were then at the back of various magazines. I did well in the ones that tested mathematical and verbal abilities but poorly in the ones that tested visuo-spatial abilities. And so it remains to this day. I still have to use a map or have someone help me to find the way when I drive to my sister, despite the fact that neither she nor I have moved home for about 30 years. Having done extremely well at chemistry all my school days, I was suddenly floored by much of organic chemistry at A-level. It is difficult to be sure, so many years later, but I think I reacted in the way many people do – I concluded that I had been wrong to think I was good at chemistry and promptly decided to drop it as soon as I could. It is possible that good teaching about both the natural differences between people and the growth mindset approach might have caused me to be less precipitous in my flight from all things chemical towards ecology.

There are a number of arguments in favour of teaching about the genetics of intelligence. The topic provides an example of 'complicated' inheritance – so is more realistic and may be more engaging for students than the simplified stories they often get. It represents cutting-edge science – in that there is still uncertainty about the role of genes in the determination of intelligence and the mechanisms by which such genes act – but it is not conceptually too difficult. It provides a good example of evo-devo, including the role of learning – stories of 'feral' children and children in certain orphanages can fascinate students and help them to appreciate just how crucial our upbringing is for determining who we are and what we can do. Finally, there are natural extensions from learning about what affects intelligence to what affects things like sporting success and musical performance.

All in all, there are a number of things we might want students to learn about the genetics of intelligence:

- Intelligence is not a simple inherited trait.
- Environments and the story of our development are important, as well as genes.
- The non-equation of heritability and determinism.
- Arguments about 'potential' and growth mindset.
- Specific points about the measurement and heritability of intelligence.
- Whether there are likely to be any practical implications of research into the genetics of intelligence – to which I return below.
- Historical instances of the misuse of genetics, allowing for explorations of socio-scientific issues and the role of ethics in science.
- Consideration of the nature of science and the history of science – including disagreements among scientists.

The use of genetics to improve education

Finally, I want to expand on the bullet point ‘Whether there are likely to be any practical implications of research into the genetics of intelligence’. As yet, genetics has contributed virtually nothing of any value to teaching. Nevertheless, it is possible that genetics might eventually prove to have some direct educational value. Consider the analogy with medicine. For a long time, understanding the genetics of diseases was of no use in treating them. Gradually, however, certain diseases with a strong genetic component became amenable to treatment as a result of such knowledge or, even better, became preventable. Nowadays we are in the early stage of gene therapy but examples exist from long before gene therapy was even a pipe dream.

A classic example is the condition phenylketonuria. Phenylketonuria is a congenital metabolic disorder in which the body is not able to manufacture the enzyme phenylalanine hydroxylase. As a result, the amino acid phenylalanine accumulates to levels in the blood that affect the brains of infants, resulting in severe mental retardation and other adverse consequences if nothing is done. In 1962, Robert Guthrie invented the test that now bears his name. The Guthrie test relies on the collection of a few drops of blood from one of the heels of a newborn. Individuals found to have the abnormalities in their blood that indicate that they will go on to develop phenylketonuria unless something is done are put on a diet that has as little phenylalanine as possible. Such diets are boring but they are used in many countries and have prevented the development of phenylketonuria in tens of thousands of people.

The example of phenylketonuria is, therefore, an example to do with the genetics of intelligence. What once could validly have been described as a disease caused by a faulty gene has now been largely eliminated though an environmental intervention. In the same way, it is possible that genetics *might* – I don’t want to put it more definitely than that – one day be used to tailor intervention programmes more precisely so that – to give just one example – instead of a 4- or 5-year-old simply being identified as slow to start reading, it would be known whether to concentrate on helping the child to distinguish between certain letters, to learn the relationships between letters and sounds, to read consistently and steadily from left to right (for left-to-right languages), and so on. Another analogy would be with spectacles or hearing aids – find the right one and learning can take off.

Acknowledgements

This article is based on a talk given at the Association for Science Education 2020 Annual Conference. I am grateful to various colleagues, especially Neil Ingram, for stimulating conversations and valuable feedback.

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