Chapter 3
How Can We Teach Genetics for Social Justice?

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3.1 The Problem

Learning about genetics can result in misconceptions; one of these is that when genetics plays a part in the development of a characteristic, that characteristic is genetically determined (e.g., Kampourakis, 2017). When such misconceptions are about matters of deep personal significance to us, such as human sexuality and intelligence, there is a danger that teaching about such issues could lead to individuals being disadvantaged and social justice retarded. Under these circumstances, one response might be to avoid such teaching in formal education at schools. However, might this amount to abdicating our responsibility as genetics educators? In addition, students are likely to have such misconceptions reinforced through what they learn from other sources, including the media (Carver et al., 2017). Could it be that good-quality genetics education in schools will not only help students gain a better understanding of genetics, but will also help advance social justice? In this chapter, I explore this idea, with particular reference to teaching about such educationally significant factors as general intelligence, reading ability and examination success.

It is well established that many people, including school students (Gericke & El-Hani, 2018) and the general public (Gadjev, 2020; Kampourakis, 2020), find the topic of genetics cognitively difficult (e.g., Kampourakis, 2017; Haskel-Ittah et al., 2020). There are many reasons for this. For a start, some of what we (as science educators) want learners to understand takes place on scales that are too small for visualisation, even with electron microscopes—the sequences of bases on DNA, in particular (cf. Marbach-Ad & Stavy, 2000; Rotbain et al., 2006). Then there is the fact that a deep understanding requires knowledge at a number of different levels—a change in DNA structure may lead to a change in protein structure, which may affect the phenotype of an organism, which may result in it leaving fewer or more

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copies in future generations, which may have consequences for the population as a whole and ultimately, the species. These levels operate over huge ranges of time and space. In addition, and related to this, some of genetics is abstract and makes high cognitive, including mathematical, demands on learners, resulting in numerous student misunderstandings (misconceptions) about genetics in particular and evolution more generally (Harms & Reiss, 2019).

In this chapter, I address an issue that has to do with difficult genetics and lies at the heart of scientific literacy, namely, the relevance of much of genetics education to the lives of learners. By relevance, I mean more than interest; I mean the extent to which contemporary school genetics education does a good job of enabling students to understand the ways in which genetics affects their lives and the lives of others—now, in the past and in the future. My particular focus, for reasons that I explain below, is the specific issue of the genetics of (general) intelligence (and related characteristics, such as reading ability); the broader context deals with how genetics can be taught for (i.e., to advance or promote) social justice. Back in 2000, I wrote an article asking whether it would be wise to undertake research on the genetics of intelligence. I concluded: "The history of the debate on intelligence does not make one very optimistic that the fruits of such research would be used wisely" (Reiss, 2000, p. 1).

I do not want my comments to relate only to my own country, so there is no analysis here of the National Curriculum for science as it applies to England, Wales and Northern Ireland, nor of school textbooks and examinations in these countries. Instead, I start with the 'Big Ideas' of science education—as articulated by Wynne Harlen and her colleagues (Harlen et al., 2010, 2015). At the time of writing, the documents about 'Big Ideas' are not as highly cited as the Next Generation Science Standards (National Research Council, 2012). However, the latter are intended specifically for the United States, whereas Harlen's 'Big Ideas' are intended internationally and have been taken up in a number of countries; they are currently perhaps the nearest we have to an international agreement on what should be in school science education (Appendix 1).

When one looks at Appendix 1—with its suggestions for Big Idea 9 "Genetic information is passed down from one generation of organisms to another"—a number of things strike me.[1] For a start, I am rather surprised now to read "other features, such as skills and behaviour, are not passed on in the same way and have to be learned." This is, at best, a major oversimplification—though I realise that one does need to simplify for 7–11 year olds, the intended age for this learning objective. But I note two bigger things. One is that, perhaps inevitably, what is written in Appendix 1 is written at a high level of generality—it is not clear, for instance, which characteristics of organisms are being talked about. The second is that there is nothing in Harlen et al. (2010) or Harlen et al. (2015) about the history of the use and misuse of genetics, or on the relative contributions of genes and the environment to the

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[1] This is not meant to be read as an attack on this Big Idea. Indeed, if I am critical, I am in large measure self-critical as I was part of the team that wrote the Big Ideas and, as a biologist, I share particular responsibility for what is in the biological Big Ideas.

determination of phenotypes—aside from the cited sentence for 7–11 year olds. It would be possible to read all of the text in Appendix 1 and conclude that characteristics are either entirely determined by genes or completely independent of them—a false conclusion that is likely to be reinforced by the introductory statement “Genes determine the development and structure of organisms.”

The nearest the Big Ideas come to acknowledging the importance of the use and misuse of genetics is in Big Idea 14: “Applications of science often have ethical, social, economic and political implications.” Here we read, for example (for 11–14 year olds), “There are generally both positive and negative consequences of the applications of science. Some negative impacts can be anticipated but others emerge from experience.” However, the examples that immediately follow have nothing to do with genetics. Indeed, there is nothing in Big Idea 14 about genetics for any student age group.

3.2 Current Knowledge About the Problem

It is widely accepted that the material, cultural and social benefits that children receive from their parents play an important role in how well they do at school. However, there is a 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 first look at why there is this disconnect and then examine the core issue of the role of genetic inheritance in school performance. As a result, I hope to show three things:

1. Genetic inheritance can contribute to how well children do in schools.
2. This does not mean that children’s school performance is predetermined, i.e., fixed in advance; environments are important too.
3. Education needs to stop putting its head in the sand about the possible role of genetic inheritance in school performance.

3.2.1 Inheritance Plays a Role in How Well Children Do in Schools

Geneticists determine the extent to which inheritance plays a role in the manifestation of a trait in much the same way, whether we are considering the height of plants, the milk yield of cows or the reading ability of children. Saying that inheritance ‘plays a role’ is not to minimise the importance of environmental factors or to ignore the ways in which environmental and genetic factors may interact. Throughout, of course, by ‘inheritance’ is meant ‘genetic inheritance’. Everyone realises, for example, that family background is important. 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. Indeed, much of the skill in arriving at measures of 'heritability'—the extent to which genetics plays a role—is precisely to do with disentangling the effects of shared environments.

Without going into a full-scale statistical treatment of how biologists and statisticians determine the importance of genes for the expression of any trait (e.g., Walsh & Lynch, 2018), what is needed is:

- to obtain reasonably objective measures of the trait in question. This is fairly easy for milk yields in cows; it is harder—but not impossible—for most things of educational interest, such as reading ability or musicality;
- to collect such data from a large number (ideally many thousands) of individuals;
- to get a measure of the extent to which these individuals have similar genetic constitutions;
- to get a measure of the extent to which these individuals have similar environmental backgrounds.

It is the last two of these that are the most difficult to achieve and for this reason, a number of human studies have relied on twin studies. Twin studies are of value because there are two sorts of twins—identical and non-identical. Non-identical twins are no more genetically similar than any two non-twin siblings but, by virtue of having 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; but, in addition, they are virtually identical genetically. What this means is that by looking at the extent to which monozygotic (identical) twins are more similar in certain traits than are dizygotic (non-identical) twins, one can obtain a measure of the heritability of a trait. In a comprehensive review of the causes of individual differences in human traits, Polderman et al. (2015) concluded that across all such traits, the reported heritability was 49%. For 69% of the traits, the observed twin correlations were consistent with a simple model in which twin resemblance is solely due to additive genetic variation: the data were inconsistent, with substantial influences from shared environment or non-additive genetic variation.

To give an extreme example (and one that oversimplifies as heritabilities are normally calculated on characteristics that vary continuously not discretely): identical twins typically have very similar eye and hair colour—more similar than is the case for non-identical twins. We therefore conclude that eye and hair colour have high heritabilities. However, the language (e.g., French, Urdu, Mandarin) spoken best by identical twins is no more similar than in the case for non-identical twins. In most cases, of course, siblings, twins or not, have the same mother tongue but if they are separated at some point in their childhood—for example, because they are adopted by families in different countries—they may end up speaking different languages best. We therefore conclude that the language one speaks best has a very low heritability.

Nowadays, there are various ways of calculating heritabilities and they give similar values—which is encouraging from a scientific point of view. A widespread consensus is that human behaviours tend to have heritabilities of about 0.3–0.6 (Bouchard, 2004). Heritabilities lie between 0 (e.g., the language one speaks best) and 1 (e.g., eye colour). 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 0.1–0.2). Examples of human behaviours include personality, intelligence, artistic interests and the chances of developing a psychiatric illness.

However, the term 'heritability' is often misunderstood. To calculate it, as the bullet points above indicate, it is necessary to look at quite a large number of individuals, and the calculated values therefore apply to the level of groups of individuals, and not to the individual level (Moore & Shenk, 2017). Indeed, it simply does not make any logical or biological sense to attempt, for any individual, to apportion its characteristics between its genes and its environment. As I once wrote:

> I was fortunate enough when an undergraduate in the late 1970s to be taught animal behaviour by Pat Bateson, among others. Pat sometimes likened the role of genes to the role of a recipe in making a cake. Genes and recipes are essential but it makes little sense to ask what proportion of a good (or a bad) cake is due to the recipe. (Reiss, 2003a, p. 51)

Moore and Shenk (2017) helpfully spell out a thought experiment from Lewontin (1974) in which plants are grown from seed under one of two sets of environmental conditions—one with high levels of nutrients and one with poor nutrients. The important point is that within each experimental set up, there is negligible environmental variation, so that any differences in, for example, plant height must be due to genetic differences between the plants, resulting in calculated heritabilities of (close to) 100% (1.0). However, there may be major differences between the results of the two experimental set ups, with, for instance, plants typically being substantially lower in height when grown in poor nutrients. So, it is a mistake to conclude that just because heritability is high, environments cannot make a difference.

Turning specifically to issues connected with 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 set up the Twins Early Development Study (TEDS) in 1994 when he moved to the UK from the United States. TEDS is now one of the largest and longest-running twin studies in the world, with about 13,000 pairs of twins in 2019.

As is well-known, twin studies have historically been of great value in inheritance research as they do not require the sort of DNA mapping that has only fairly recently become widely available (and affordable). Estimates of heritability can be made using data from monozygotic twins reared apart (but there are only a few hundred such pairs of twins who have been studied) or by using data from monozygotic twins brought up together and from dizygotic twins brought up together.

Today, other approaches, in addition to twin studies, are becoming increasingly valuable for determining human heritabilities. In particular, the rapid decrease in the cost of DNA sequencing means that it has become possible to screen large numbers of people (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.

One conclusion from these various studies seems clear: it is no longer possibly to validly conclude that genetics plays no part in educational success (e.g., Morris et al., 2018; Savage et al., 2018; Sniekers et al., 2017). For example, in the UK, there is a genetic component to university examination success (Smith-Woolley et al., 2018). Furthermore, it is not just ‘intelligence’ that is heritable. For instance, genetic factors are implicated in mathematical anxiety (Wang et al., 2014).

However, it may be that the standard ways of calculating heritabilities underestimate the importance played by the environment and therefore overestimate the importance of genetics (Rosenberg et al., 2018). Twin studies often produce higher estimates of heritabilities than do genome-wide association studies, which suggests that, despite the best efforts of those undertaking twin studies research, it remains difficult to untangle the effects of genes and the environment. We are in the early days of research on the genetics of intelligence and it is very possible that some of today’s confident assertions will be tempered by time.

3.2.2 Children’s School Performance Is Not Predetermined

As every biology educator knows, calculating heritabilities and stating that differences between genes are involved in school success does not mean that genes alone are important—an organism’s genes do not *determine* its characteristics. For a start, there is the obvious truth that genes need the rest of the cell to work. Then there is the fact that we could just as well talk about the roles that proteins (and other gene products) play in school success. There are two biologically valid reasons for why we more usually talk about genes: it is genes that are inherited; and the Central Dogma (DNA makes RNA makes proteins), so that changes to RNA or protein structure that are not the result of changes to DNA structure are not passed on to the next generation.

Even those who emphasise the importance of genetics in the development of human characteristics fully acknowledge that sometimes, genetics plays less of a role than is commonly presumed. Plomin himself 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).

Then, focusing on intelligence, there is the well-known Flynn effect. Throughout the twentieth century, there were steady and substantial 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. That is not much year to year, but over the twentieth century, it amounts to 25–30 points, almost two standard deviations. A number of factors are believed to contribute—better health, better education, better nutrition among them—but the important point is that such data emphasise the extent to which intelligence has an important environmental component (cf. Bratsberg & Rogeberg, 2018). Flynn's more recent work explicitly attacks the notion that genetics is of overriding importance in the determination of intelligence (Flynn, 2016).

It is hardly surprising that education enhances intelligence. But it might be that students with a greater propensity for intelligence go on to complete more education, or that more years of education increase intelligence (Ritchie & Tucker-Drob, 2018). In a large (over 600,000 participants) meta-analysis, Ritchie and Tucker-Drob (2018, p. 1358):

> found consistent evidence for beneficial effects of education on cognitive abilities of approximately 1–5 IQ points for an additional year of education. Moderator analyses indicated that the effects persisted across the life span and were present on all broad categories of cognitive ability studied. Education appears to be the most consistent, robust, and durable method yet to be identified for raising intelligence.

Some of the most trenchant criticism of the argument that genes are important determinants of educational success has been raised by the veteran biologist, Steven Rose. One of Rose's key points is that calculations of heritability depend on the extent to which the environment varies in some relevant way—this is well-known but easy to forget (Rose, 2014). A classic example is that human height shows higher heritability in high-income countries than in low-income ones where 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 makes 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; cf. Tucker-Drob & Bates, 2016).

3.2.3 Education Needs to Stop Ignoring the Possible Role of Genetics in School Performance

Ever since the publication of Darwin's momentous *On the Origin of Species* in 1859, biologists have accepted that inherited variation plays a central role in the manifestations and evolution of the enormous number of characteristics exhibited by organisms. The early twentieth century advances in genetics, followed by the mid-twentieth century advances of neo-Darwinism and the subsequent developments in molecular biology, have emphasized this conclusion (Klug et al., 2019; Roberts et al., 2000).

In the case of humans, along with other organisms, this means that just about everything of interest about us has an inherited component. It does not matter whether one considers height or weight or reaction time or longevity or the likelihood of developing heart disease or anything else, inheritance generally plays a role. And this is true, too, of such educationally significant factors as general intelligence, reading ability and examination success. This, of course, is not to ignore the influence of environmental factors on all of these characteristics.

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, with certain exceptions (e.g., Ingram, 2019), educators have generally been reluctant, to put it mildly, to accept the mounting weight of evidence for the importance of genetic inheritance in school performance (e.g., White, 2006). There are a number of reasons for this reluctance—most of them understandable and indeed well-intentioned.

For one thing, there is a terrible legacy of genetics and human history. Historians of science and evolutionary biologists (e.g., Gould, 1981; Lewontin, 1991) have shown how genetics has been used, both consciously and unconsciously, in attempts to argue for the inferiority of women, of black people and of those not in the ruling classes. Faced with this legacy of sexism, racism and cultural imperialism, it is hardly surprising that educators have rejected genetics as a way of understanding differences between humans. What has happened is that genetics, rather than the misuse of genetics, has been rejected. It is as if books in general were rejected because some books are harmful. The reality, though, is that a *better* understanding of genetics, not the *abandonment* of genetics, is what is needed.

A second major reason for the widespread scepticism among educators, certainly in the UK, concerning the importance of inheritance in educational attainment is due to the legacy of Cyril Burt. Cyril Burt (1883–1971) was an educational psychologist who played an important role in the development of an examination (the ‘11-plus’) in schools in England to determine whether students were educated from the age of 11 in more (grammar schools) or less (secondary modern) academically demanding schools. Although there have been quite a number of revisionist accounts (e.g., Fletcher, 1991; Tredoux, 2015), it is generally thought that Burt 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 at the time (Rushton, 1997). In other words, even if we ignore all of Burt’s work, there would be no effect on the conclusions to be reached from the literature about the role of inheritance in the manifestation of intelligence, namely that inheritance and the environment both play a part (Johnson, 2010).

A third major reason why educators have tended to ignore the ever-increasing growth in what is known about the inheritance of intelligence is, I believe, due to the widespread, often implicit, presumption that *inheritance* is to be equated with *determinism* (e.g., Gericke et al., 2017; Jiménez-Aleixandre, 2014; Kampourakis, 2017), as discussed above.

3.2.4 Social Justice in Science Education

Traditionally, there have been two main aims for school science education. The majority aim has simply been for students to come to a good knowledge and understanding of science, typically understood as both the content of science (the specifics of biology, chemistry, earth science and physics) and the way in which science is undertaken (often referred to as the nature of science). The second aim has been that school science education should in some way contribute to the well-being of both the individuals who are learning it—now and/or in the future—and more collectively, society (Reiss & White, 2014).

This second aim can be characterised in a number of ways but one that has a good pedigree is 'science for social justice' (Reiss, 2003b). Social justice is about the right treatment of others [what Gewirtz (1998) identifies as the relational dimension of social justice] and the fair distribution of resources or opportunities (the distributional dimension). Of course, considerable disagreement exists about what precisely counts as right treatment and fair distribution of resources. For example, some people accept that an unequal distribution of certain resources may be fair provided certain other criteria are satisfied (e.g., the resources are purchased with money earned, inherited or obtained in some other socially sanctioned way—such as gambling in some, but not all, cultures). At the other extreme, it can be argued that we should ensure either that all resources be distributed equally or that all people have what they need. Such distributions might be achieved through legislative coercion, social customs or altruism on the part of those who would otherwise end up with more than average.

An important element of teaching for social justice is what Freire (1970) termed 'conscientization' (or 'consciousness raising'). This can be seen in feminist pedagogy, where students develop the ability to question gendered inequities and their causes and perpetuation, in anti-racist education, in education that seeks to undermine heteronormativity, in critical pedagogy in general and in science education more specifically (Reiss, 1993).

Teaching in school science for social justice should help promote flourishing, for both humans and other organisms, and for the environment more generally. We want, for example, people to want other people, as well as themselves, to live fulfilling lives. Negatively, this means not hurting them, not lying to them, not breaking one's word or in other ways impeding them in this. Positively, it means helping them to reach their goals, respecting their autonomy and being fair, friendly and cooperative in one's dealings with them. Schools can reinforce and extend what parents and others family members do in developing morality in children, and school science has a particular place in this given the fact that many contemporary ethical issues have a techno-scientific element to them (genetic modification, climate change, artificial intelligence, etc.). Schools can expand students' moral sensitivity beyond the domestic circle to those in other communities, locally, nationally and globally, and beyond this to other species and the whole of the environment.

Specifically with reference to teaching about educational success, there is a risk that teaching about the role of genetics in this might backfire, causing students to conclude that their educational ability is ‘fixed’ and that it is not worth them bothering much if they are doing poorly in school. This, of course, would retard rather than advance human flourishing. One possible response, therefore, is to continue to do what is being done at present, which is to avoid consideration of the issue. But I think that there is a risk to this response; in failing to address students’ misconceptions about genetics in general and the genetics of educational success in particular, an opportunity is lost. My hope is that good-quality genetics education might enable students to reject the mistaken conclusion that educational ability is ‘fixed’.

3.3 Remaining Issues

While there is, in my judgement, no doubt that there is a genetic component to educational success, several points need to be made. For a start, 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 single nucleotide polymorphisms (SNPs) (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.

Then there is the fact that, as yet, understanding *how* certain genes affect cognitive and/or educational performance—i.e., their mechanisms—is only beginning. I have no doubt that these mechanisms will increasingly be worked out and that such elucidation will help reduce some of the over-the-top claims *and* fears around genetic influences; however, much remains to be done.

Perhaps the most important educational issue that remains is whether advances in genetics will prove to be of value in enabling educational interventions. I discuss this possibility in the section below ‘Genetics and better diagnoses of educational issues’.

3.4 Implications for Teaching

Understood badly, realisation of the importance of genetics for education can paralyse teachers and students, leading them to think, mistakenly, that there is little that can be done to counteract the effect of genes. In this section, I discuss two main ways in which this belief is mistaken, firstly by discussing the ‘growth mindset’ movement and secondly, and more speculatively, by suggesting how genetics might one day be used in better diagnoses of educational issues.

3.4.1 The Growth Mindset Movement

'Growth mindset' refers to a learning theory most associated with the work of Carol Dweck. The key idea is that if learners believe that they can improve their performance (intelligence, subject attainment, skills, examination success and the like), they will do better than if they believe that their performance is predetermined (Dweck, 2017). When Dweck was a child in her 6th-grade class in Brooklyn, New York, students were seated in order of their IQ. Students with the highest IQ scores could erase the blackboard, carry the flag or take a note to the principal's office. In a 2015 interview, Dweck pointed to this 'glorification' of IQ as a key point in her childhood.

Dweck (2017) argues that individuals vary with respect to where they believe ability comes from, falling somewhere on a continuum with two endpoints. At one extreme, those with a 'fixed' mindset believe that ability is innate, and can be changed only a little. At the other extreme, those with a 'growth' or 'incremental' mindset believe that success comes from hard work and persistence. Dweck and her colleagues maintain that encouraging a growth mindset in students results not only in them learning more but also in better self-regulation, increased wellbeing and reduced helplessness.

As a teenager, despite doing very well at mathematics and the sciences and reasonably well at English, with a passion for reading, I had convinced myself that I was not good at languages. In hindsight, it was simply that my performance at French and Latin—the two foreign languages I had been taught for many years—was mediocre, which probably says as much about my teachers as myself. I can still recall the first lesson I had at school (aged 13) in German. The teacher burst into the classroom and proceeded to speak only German. At the time this seemed revolutionary to us. "Ich bin Herr Martin. Wer bist du?" he began. By the end of the lesson we were all speaking a few simple phrases and I proudly said to my grandmother (who was German) when I next saw her "Das ist ein Kugelschreiber," as I took a biro from my jacket pocket. German ended up being one of my two best 'O' levels (examinations taken in England at that time at the end of compulsory schooling) while Latin was my worst, with French not much better. Having previously presumed that I suffered from some sort of innate shortcoming at languages, I now realise that this was not the case.

There is mounting evidence that interventions can enable students to move towards more of a growth mindset position, though not all interventions have proved successful (e.g., Foliano et al., 2019). Yeager et al. (2019) found that an online growth mindset intervention that took just under one hour and taught that intellectual abilities can be developed improved grades among lower-achieving students and increased overall enrolment in advanced mathematics courses in students in school education in the United States. The effect size was not large (0.10) but the sample was nationally representative and given that the intervention took under an hour, it represents excellent value for money; in addition, an effect size of 0.10 equates to about 6 months of progress with an average teacher.

Not everyone is convinced by the growth mindset argument. The same Robert Plomin who has done so much work on the genetics of intelligence and educational success is unimpressed with it:

> Growth mindset, I feel, is greatly over-played…If you try to tell kids who have trouble learning, "You can do it, you can change," you can actually do some harm. Because some kids are going to find it really difficult; it isn't just a matter of positive thinking. Kids aren't stupid. I don't believe the evidence base is all that strong. (Lee, 2015, p. 12)

Of course, defenders of the growth mindset argument would respond by saying that Plomin's characterisation of it as "you can change" at best misunderstands what growth mindset is all about (at worst, the phrase itself suggests an essentialist conception of individual performance that is precisely what growth mindset rejects). It is not a matter of students who are performing poorly "changing"—a sort of naïve positive psychology. It is about all students putting into practice the notion that each of us needs to persist and practise, thereby improving our performance. Such teaching requires appropriate resources and caring teachers. It is known that STEM faculty who believe that ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes (Canning et al., 2019).

3.4.2 Genetics and Better Diagnoses of Educational Issues

It needs to be emphasised that, as yet, genetics has contributed virtually nothing of any value to teaching. Indeed, because of the common, albeit mistaken equation of genetics with destiny (the belief that genes are determinative), it is more likely that genetics has harmed education. 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 treatable or, even better, preventable as a result of such knowledge. We are now in the early stages of gene therapy, but examples exist from long before gene therapy was even a pipe dream.

A classic example is the condition phenylketonuria, 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 left untreated. In 1962, Robert Guthrie invented the test that now bears his name, replacing a pre-existing but less effective test. The Guthrie test relies on the collection of a few drops of blood from one of the heels of a new-born. 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 is low in phenylalanine. Used in many countries, this has prevented the development of phenylketonuria in tens of thousands of people.

In the same way, it is possible that genetics might 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 distinguish between certain letters, learn the relationships between letters and sounds, read consistently and steadily from left to right (for left-to-right languages), etc. Another analogy would be with spectacles or hearing aids—find the right one and learning can take off.

3.4.3 Genetics Education

Finally, there are implications for genetics education. There isn't space here to flesh out a whole curriculum but, from the above literature and arguments, teaching about the genetics of intelligence might have a number of benefits:

- It provides an example of 'complicated' inheritance—so is better and possibly more interesting for students than the simplified stories they often get.
- It represents cutting-edge science.
- It provides a good example of evo-devo, including the role of learning (e.g., 'feral' children, children in certain orphanages).
- It has lessons for things like sporting success and musical aptitude.

There are a number of things we might want students to learn about the genetics of intelligence:

- intelligence is not a simple monogenic trait (cf. standard accounts of blue eye colour, phenylketonuria, cystic fibrosis, etc.) but a complex trait that is influenced by interactions between polygenic and environmental factors, including the family and the society in which one grows up;
- the distinction between heritability and determinism;
- growth mindset arguments and our ability to improve, given appropriate resources, support from others and effort on our part;
- whether there are likely to be any practical implications of research into the genetics of intelligence, reading ability or musicality;
- there have been and continue to be many instances of the misuse of genetics to the disadvantage of women, minority groups and those in general who are not in positions of power and privilege.

Teaching about the genetics of intelligence can therefore allow for explorations of socio-scientific issues and the role of ethics in science. It also potentially provides a good entry into consideration of the nature of science and the history of science—including disagreements among scientists. Nevertheless, it is important to emphasise that many people have a deterministic understanding of the genetics of human behaviour in which genes are presumed simply to 'cause' characteristics (e.g., Lynch et al., 2018). If done badly, teaching about the genetics of human characteristics might not only fail to overturn such misunderstandings; it might reinforce them.

In a classic study, Dar-Nimrod and Heine (2006) showed that women who read a passage about genetic causes of sex differences subsequently performed worse on math tests than those who read about experiential causes. Teaching matters.

3.4.4 Conclusion

There are many ways that good teaching, including good science teaching, might hope to advance social justice. We now have the beginnings of a literature compendium as to how genetics education can be of high quality and help to advance genetic literacy (Boerwinkel et al., 2017; Dougherty, 2009; Nowgen Centre, 2012) and, in particular, social justice, for example by tackling issues to do with determinism (Clément & Castéra, 2014), race (Sheth, 2019) and sex differences (Donovan et al., 2019). The argument of this chapter is that done well, good biology teaching about intelligence can help all learners learn well and flourish. However, done badly, genetics education can have the opposite effect.

Appendix 1

Genetic Information Is Passed Down from One Generation of Organisms to Another

Genetic information in a cell is held in the chemical DNA. Genes determine the development and structure of organisms. In asexual reproduction all the genes in the offspring come from one parent. In sexual reproduction half of the genes come from each parent.

5–7 years old

Living things produce offspring of the same kind, but offspring are not identical with each other or with their parents. Plants and animals, including humans, resemble their parents in many features because information is passed from one generation to the next.

7–11 years old

Other features, such as skills and behaviour, are not passed on in the same way and have to be learned.

11–14 years old

Inside the nucleus of animal and plant cells are structures called chromosomes which hold large complex molecules of DNA. When cells divide the information that is needed to make more cells is in the form of a code represented in the way that the parts of the DNA molecule are put together. A gene is a length of DNA; and hundreds or thousands of genes are carried on a single chromosome. In the human body most cells contain 23 pairs of chromosomes with a total of about twenty thousand genes.

When a cell divides, as in the process of growth or replacement of dead cells, genetic information is copied so that each new cell carries a replica of the parent cell. Sometimes an error occurs in replication, causing a mutation, which may or may not be damaging to the organism. Changes in genes can be caused by environmental conditions, such as radiation and chemicals. These changes can affect the individual but only affect the offspring if they occur in sperm or egg cells.

In sexual reproduction, a sperm cell from a male unites with an egg cell from a female. Sperm and egg cells are specialised cells each of which has one of the two versions of each gene carried by the parent, selected at random. When a sperm and egg combine half the genetic material in the fertilised egg is from the sperm cell and half from the egg cell. As the fertilised egg divides time and time again this genetic material is duplicated in each new cell. The sorting and recombining of genetic material when egg and sperm cells are formed and then fuse results in an immense variety of possible combinations of genes, and in differences that can be inherited from one generation to another. These provide the potential for natural selection as a result of some variations making organisms better adapted to certain environmental conditions.

14–17 years old

Asexual reproduction, which occurs naturally in a wide range of organisms including some bacteria, insects and plants, leads to populations with identical genetic material. Biotechnology has made possible the production of genetically identical organisms through artificial cloning in a range of species including mammals.

The overall sequence of genes of an organism is known as its genome. More is being learned all the time about genetic information by mapping the genomes of different kinds of organisms. When sequences of genes are known genetic material can be artificially changed to give organisms certain features. In gene therapy special techniques are used to deliver into human cells genes that are beginning to help in curing disease.

Taken from Harlen et al. (2015, p. 28)

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