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ARTICLE

Must Introductory Genetics Start with Mendel?

Lessons from Two Unsuccessful Attempts to Revise the Genetics Curriculum

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Abstract
It is 157 years since Mendel presented his results on hybridisation in peas to the Brünn Society for Natural Science. The discipline of genetics has dramatically changed since then, with technological advancements revealing multifactorial causation and trait variability. Whilst none of this complexity featured in the discovery of classical genetics, Mendel and his peas still dominate teaching today. Must genetics always start from such a simplistic, determinist perspective? A number of recent studies (e.g. Donovan, 2021; Dougherty, 2010; Jamieson & Radick, 2013) have made the case for emphasising the complexity of genetics from the beginning. In this study, I will examine the origins and fate of two earlier attempts at reform, from the 1970s and 1980s. One was from Steven Rose, a biochemist in London and founder of the British Society for Social Responsibility in Science, who developed a genetics course for distance teaching at the Open University. The other was from Garland Allen, a historian of science and influential writer of biology textbooks, including four editions of *Study of Biology*. Both tried to depart from the standard start-with-Mendel script, in ways that aimed to help students better appreciate not only the complexities of genetics but also embedding genetics—and genetic knowledge—in society. Both met significant resistance, with concerns varying from the creation of unrealistic demands on students to the time and cost of making large-scale changes to textbooks. In closing, I will suggest that the experiences of Rose and Allen hold valuable lessons for reformers of the genetics curriculum today.

1 Introduction

We are now in the age of genomics, where the genome of entire organisms can be sequenced. We know far more about genetics, inheritance and developmental processes than we did in 1900 when Mendel's set ratios were rediscovered. Why, then, do Mendel's laws of inheritance, which only occur in specific instances, remain at the core of school and

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university level genetics curricula? Science education is challenged by tensions between the subject's complexity and accessibility, and the presentation of its nature as established theories whilst constantly growing. Venville et al. (2005) highlight the duty teachers and researchers have in providing the most genuine introduction to genetics. With genetic technology increasingly impacting society, an up-to-date scientific literacy is necessary for students to respond to modern-day issues, such as modified crops and the genetic engineering of animals and humans. Yet, an inaccurate presentation of the history of modern genetics is revealed by analysing the development of textbooks, where Mendel represents a universal, fixed conception (Sparks et al., 2020). The timing of discoveries, as well as the journals, articles and textbooks which communicate them, impacts the presentation of science. In genetics, the development of deterministic attitudes has been reiterated by teaching the outdated dichotomy of Mendelian laws (Jamieson & Radick, 2017). There is a recent drive for curriculum reform to highlight the social and historical context which led to Mendel's success and reflect advancements in genetics, representing a more insightful historiography and pedagogy of science.

1.1 Mendelism

The magnitude of Gregor Mendel's findings cannot be understated as he developed principles of inheritance before knowledge of genes existed. The Austrian botanist (1822–1884) spent 8 years experimenting with seven heritable characteristics in the pea, *Pisum sativum*, in the garden of a monastery in Brno. During this time, he is thought to have developed three fundamental laws. Notably Mendel deduced the existence of 'dominant' and 'recessive' traits by crossing true breeding plants (where both alleles for a gene are the same) for different versions of the same trait, resulting in the offspring expressing one version *over* the other. An example was flower colour, in which Mendel found that crossing a purple-flowering pea plant (PP) with a white-flowering pea plant (pp) produced purple-flowering plants (Pp), indicating purple as the dominant trait. He continued by crossing two of the 'hybrid' generation (with one allele for white flowers and one for purple flowers, Pp) and noticed that over a range of subjects, this produced purple- to white-flowering plants in a 3:1 ratio (Bowler, 1989). This led to what is now labelled as the *law of dominance*, that an individual will always express the dominant form of a gene if present. Other observations in this time underlie the *law of segregation*, that genes for a trait exist in pairs, with one inherited from each parent, and the *law of independent assortment*, that the inheritance of one gene is not affected by another ("Mendel as the Father of Genetics: DNA from the Beginning", 2021).[1] This led to a new science of inheritance which was first labelled *Mendelism* and is now commonly known as *genetics* with Gregor Mendel filling a position of the 'father of genetics' as often described in textbooks (Bowler, 1989).

The impact of Mendel varied across time and place. Hybridists before Mendel are reported to have some awareness of genetic dominance and hybrid segregations (Olby, 1966, p. 9). Furthermore, the discipline of 'genetics' formed many years after Mendel's death, and his report describing the results from these hybridisation experiments only had an impact when 'rediscovered' 34 years later alongside botanists Hugo de Vries, Carl

[1] It must be noted that Mendel did not present his work as three explicit laws, but that work from others such as de Vries and Correns led to the construction of what is known now to be 'Mendel's laws'. For example, Mendel's law was the 'law of combination of different characters', which we now refer to as the law of independent assortment (Olby, 1996, p. 139).

Correns and Erich von Tschermak who claimed to independently discover the same laws. Olby (1966) suggested that the 34-year neglect of Mendel's results was due to a lack of contact with scientists in Britain, as well as concerns of presenting a concept of heredity less variable than any Darwinian would accept. These years of silence may have either limited scientific progress or indicate that later scientific developments were used to explain earlier observations (Müller-Wille, 2018, p. 4). In 1930s in Russia, the widely endorsed Trofim Lysenko argued against Mendelism, supporting the inheritance of acquired characters. This theory also dominated French evolutionary ideas, leading to a resistance of Mendelism until after the success of molecular biology. Lucien Cuénot contributed to 'Mendelian' genetics, but ultimately developed genetics in France with a 'distinctively physiological perspective' (Burian et al., 1988, p. 373). Mendelian genetics was abandoned as an approach in France, and it was not until after World War II when Mendel's laws revived as French geneticists Ephrussi, Jacob and Monod, with backgrounds of non-determinant growth and developmental views of inheritance, reported findings of gene expression. Coming from this physiological stance, and a concern with cytoplasmic 'or, more generally, "non-Mendelian" inheritance', they advanced the school of molecular genetics while ignoring the strict tradition of classical genetics dominated by Mendel's dichotomy (Burian et al., 1988, p. 359).

Whilst French biology and molecular biology developed out of physiological and causal-embryological traditions, the emergence of genetics in Britain and the USA is thought to have aligned with the burgeoning interest in eugenics, leading to the celebration of a fixed, hard heredity (Bowler, 1989). The aim to eliminate 'weak' groups of society represented by the eugenics movement is argued to have provided the need for theories which promote the role of heredity over environment in human development. Described by Bowler, eugenics created 'a climate of opinion in which this kind of hereditarian theory could flourish' (1989, p. 168). Increased government funding for agricultural research was made possible by The Adams Act of 1906, allowing farms and breeders to explore different breeding methods and practices which further helped propagate Mendel's version of inheritance in the USA (Skopek, 2008, p. 46). The contrast shows that the reception of theories depends on how the scientific inquiry fits in a particular place and time, namely other 'diverse and fruitful research traditions' (Burian et al., 1988, p. 358). Müller-Wille claimed sources from Mendel have been edited 'with an accompanying scholarly apparatus', suggesting an alteration of his findings. Mendel's report is believed to be 'one of the most heavily scrutinised texts in the historiography of biology' and there remains much controversy over what he discovered (Müller-Wille, 2018, p. 9).

Nonetheless, whilst historians of science deliberate whether Mendel was a genius or a fraud, education has idolised his experiments as explaining all of human inheritance. This began with the English biologist William Bateson, who presented Mendel's results in this way. The discipline of genetics in Britain and the USA emerged from a larger conflict over the nature of evolution as either continuous (biometricians) or discontinuous (Mendelians). Bateson led the Mendelians in an ongoing dispute with Walter Frank Raphael Weldon and Karl Pearson, leaders of the biometricians, stemming from conflicting social backgrounds, sociopolitical interests and scientific training. When the biometrician-Mendelism conflict emerged in 1900, neither leaders were willing to change their outlook (Kim, 1994). Concerning inheritance, the biometricians claimed factors of inheritance are blended, while Mendelians argued they must be segregated (Hagstrom, 1995). Mendel's work was used by the Mendelians to dismiss biometrical models of inheritance 'and to underwrite the efforts of the mutationists' (Brannigan, 1979). The implications for the interpretation of heredity have been reflected in textbooks ever since, beginning with a dispute that may

have meant Mendelians reformulated 'an initially simplistic theory' to fit with their argument (Hagstrom, 1995). Weldon attacked Mendelism in the 1st volume of *Biometrika*, as he recognised the oversimplification of Mendel's results, that peas were not either wrinkled *or* smooth, yellow *or* green, but displayed continuous variation dependent upon the interaction of heritable genes, as well as environmental conditions (Radick, 2015). This lead to Bateson's response: *Mendel's Principles of heredity, a defence*, the first textbook presentation of the elementary facts of genetics (Bateson, 1902; Weldon, 1902a and 1902b). In this textbook, Bateson criticised Weldon while portraying Mendel's work in relation to his own. In fact, Bateson is reported to have been ready to accept that Mendel's laws did not apply in the case of continuous variation. However, due to 'the pressure of Weldon's criticism' he developed his argument to claim *all* evolutionarily significant characters were controlled by the discontinuous mode of heredity (Bowler, 1989, p. 119). Weldon failed to publish his interpretation of Mendel's results before dying in 1906, and Pearson made some attempts but died a sceptic of Mendelism in 1936 (Hagstrom, 1995).

Without Bateson's main opponents in Britain and the USA, he was able to present Mendel's findings in a way which ignored any complexity, impacting genetics education ever since. Other contributions to Mendel's success emanated from respected scientists and followers of Bateson: Edith Rebecca Saunders and Reginald Punnett, who carried out further breeding experiments and extended Mendel's principles onto different plant species and poultry (Dunn, 1991, p. 66). Bateson established a genetics school at Cambridge, was appointed a professorship of biology and eventually became director of the John Innes Horticultural Institution at Merton where he brought geneticists and practical breeders together (Sapp, 1987). Meanwhile, Weldon's version of a continuous heredity was overlooked, and his suspicion of Mendel's results ignored (Bowler, 1989). Thus, the rediscovery of Mendel's genetics in British science effectively depended on which side 'won'. It has been argued that 'the Mendelism that was victorious by 1910 was not the same as the Mendelism of 1900', implying that Mendel's findings were manipulated to justify a line of thinking (Hagstrom, 1995, p. 408). The science we teach in textbooks is based on the influence of British science, and its relationship with politics and society.[2]

1.2 Mendelian Curricula

Unsurprisingly then, educators, research scientists and historians of science have raised issues with a Mendelian curriculum (Smith & Gericke, 2013, p.154). In recounting his own aim of finding the statistical relations of the various hybrid offspring, Mendel admits testing thirty-four varieties of pea for the purity of type and suitability as research material, stating: 'The value and utility of any experiment are determined by the fitness of the material to the purpose for which it is used' (Olby, 1966, p. 115). Mendel intended to find a method for the production of true breeding plants from hybrids, using highly selected specimens to obtain his results. He did not intend to explain human inheritance; thus, the application of his pea-hybridisation experiments to modern genetics and universal laws is based merely on assumptions (Bowler, 1989). Mendel, Bateson and other early Mendelians

[2] It must be noted that the continuous (biometricians)/ discontinuous (Mendelians) debate primarily concerned British science, and that new disciplines such as cell theory and experimental embryology were the focus in Germany and other European biologists. Americans looked to experimental biology to help 'pave the way towards modern genetics' (Bowler, 1989, p. 78; Garland Allen, 1978). This highlights the problem with Mendelism dominating American textbooks, as I will later discuss.

had no knowledge of genes or any mechanism of heredity, using only the breeding experiments to promote their theories. Yet, the depiction of Mendel's genetics in textbooks since has stressed fixed laws of inheritance and ignored the role of nature and variability. Jacquard (1981) likens this issue to bricks and cement in forming a wall, stating that without the interaction between the two, there would be no wall. Ongoing research since the 1900s has demonstrated there is too much of a 'causal distance' between the chromosomes and phenotype to be able to specify the genes causing particular traits; thus, inheritance of most phenotypic traits cannot be as simple as Mendel's peas (Dupré, 2005, p. 199). For example, Rodgers (1991) suggested fewer than one-third of human clinical genetic conditions fit the dominant-recessive pattern.

Overemphasising the dominant-recessive pattern within a Mendelian teaching of inheritance nurtures a genetic deterministic approach: 'the idea that the genes solely determine physical characteristics or behaviours rather than in combination with other factors' (Smith & Gericke, 2013, p. 158), and leaves students to believe there is a gene 'for' traits. For example, whether or not one has blue eyes depends only on receiving 'dominant' or 'recessive' genes from each parent. Gericke et al. (2017) acknowledged that genetic determinism is both an 'educational problem' by contradicting scientific knowledge and current research in developmental processes and epigenetics, and a 'societal problem', evident in recent decades.

Thinking deterministically is thought to have influenced and been encouraged by the eugenics movement in Britain and the USA, aimed at limiting the reproduction of certain intelligence, classes and abilities, to fashion a fitter population. Sir Francis Galton, a biometrician involved in the development of eugenics, was convinced in the importance of a non-blending heredity. He believed that good genes, including those for intelligence, were concentrated in the English upper classes. If desirable traits were fixed and hereditable, they could be magnified by selective breeding. Associating other characteristics to Mendel's simple 'dominant' and 'recessive' patterns led to geneticists aiming to prove that human characteristics, such as poverty, moral degeneracy and alcoholism, were inherited in the same way. This led to laws which authorised the sterilisation of 510,000 people across Germany, the USA and Sweden, in the hope to reduce transmission of these 'hereditary diseases' (Castéra et al., 2013). This form of determinism has also been argued to underlie the Nazis' attempts to 'purify' the Aryan 'race' and the Second World War (Bowler, 1989, p. 154; Séralini, 2003). The effects of genetic deterministic thinking continue to persist in education policies where students have access to a different quality of education, depending on a supposed fixed inheritance of intelligence quotient (IQ). Some claim IQ can be separated into genetic and environmental components, and Arthur Jensen even suggested a statistical tool to analyse how much individual differences in a trait can be accounted for by genetic factors (Deary et al., 2009; Jensen, 1969). As a result, he argued education must focus on developing specific skills, rather than unsuccessfully trying to enhance IQ for those without the gene for it. Organising education by intelligence began in the 1940s in England and Wales, and the tripartite system remains in Northern Island today. Psychologist Sir Cyril Burt was influential in this establishment believing different skills needed different schooling, as educational ability was inherited and therefore fixed (Trueman, 2015). That intelligence is predetermined and fixed also leads to setting by ability within schools, which research shows is damaging to all students, particularly those placed in lower-ability groups (Belfi et al., 2012; Muijs & Reynolds, 2005). Furthermore, grouping in this way normalises separation by perceived traits and 'intensifies and solidifies' disparities in performance later on (Chambers, 2009, p. 427). Adhering to determinism may lead to students

limiting themselves in situations where they believe they do not have the certain gene 'for', such as intelligence or musical abilities, or the characteristics to belong to a certain 'group'.

Additionally, Donovan (2022) discusses the idea of 'genetic essentialism' as a form of racial prejudice, where people may think races differ at the genetic level. He suggests that it is encouraged by current genetics education, which overlooks the 'complex interplay between genes and environments' (Donovan, 2022, p. 3). One example is the case of increased prevalence of the allele for sickle cell anaemia in people of African descent. It is presented in textbooks as a disease tied to race, as assumed to align with predetermined categories (Kwateng, 2014). However, the increased prevalence in certain populations is because the gene responsible for sickle cell anaemia also provides immunity to malaria, which is advantageous in certain geographical locations (Bowler, 1989; Kwateng, 2014). Thinking deterministically when discussing genetic diseases across racial groups may lead to students perceiving more genetic variation between races than there is and could be used to promote inequality (Dorothy Roberts, 2014; Sparks et al., 2020). An example in history is when Jensen, a well-educated psychologist, suggested black and white races have different intellectual potentials, maintained by a fixed form of heredity (Bowler, 1989, p. 169). From genome analysis, we now know there is very little variation between populations; in fact, there is more within them (Reich, 2018). If students learn to classify traits into distinct groups following Mendel's laws, this can lead to an idea of 'white' and 'black' as discrete biological variables (Gannon, 2016). Reducing the racial bias evident in genetics curricula and promoting the variability of expression and the environment may help to overcome the misconception that race is a biological rather than a social construct (Donovan, 2016; Marks, 1996). Perceiving the inheritance of discrete, fixed traits may also lead to supporting gender inequality in society, as well as certain 'feminine' or 'masculine' tendencies. Determinism within the genetics education has been thought to assist the social-cognitive bias, where science ability is portrayed as innate due to the differences in genes and brains of men and women (Donovan et al., 2019).

A deterministic portrayal of genetics appears to be common amongst school textbooks across the world which maintain the idea of a one-to-one gene-to-trait ratio (Castéra et al., 2008; dos Santos et al., 2012; Gericke et al., 2014). In an age of increasing integration and diversification, the curriculum must move to conveying science honestly and using textbooks to highlight both successes and flaws of research in genetics, rather than simply idolising certain scientists and their findings. We must develop the representation of classical genetics, removing the genetic code as the ultimate determining 'blueprint' of humans, and explore genetics in line with recent developments such as gene expression and the role of the environment (Dawkins, 1976). Scientists from other disciplines including embryologists and physiologists have rejected heredity as 'self-perpetuating determinants', noting how embryonic differentiation and regulation cannot be explained by the behaviour of genes which were the same in every cell (Sapp, 1987, p. 49). Rather than explaining the entirety of human inheritance, Mendelian patterns of dominance concern special instances where other genes and environmental factors are not involved, which in humans is rare. While Mendel's laws are still relevant today, they only hold under prescribed conditions ignoring factors such as linkage, crossing-over and polyploidy realised after 1900 (Olby, 1966). Therefore, Mendelian principles should not be the predominant focus of an education in genetics, but a part of the larger approach to heredity and depicted as *stepping stones* towards the more recent discoveries in the present genomic age (Bowler, 1989).

Smith and Gericke recommended addressing genetic determinism through 'careful use of language and explicit recognition of the fallacy' (2013, p. 166). Another solution has been to present an alternative, less popularised interpretation of Mendel's findings

in Britain such as Weldon's (Jamieson & Radick, 2017).[3] The study at the University of Leeds emphasised the mechanism of heredity as a developmental process, and how traits depended on interactions between genes and their developmental context (Jamieson & Radick, 2017). The professors found students following a Weldonian course held less deterministic attitudes to heredity, than those studying the standard Mendelian genetics course. The concise nature of textbooks often results in oversimplification of inheritance and exclusion of the historical context as the author aims to cohere with the time constraints of education and exam-based teaching. However, these oversimplified examples may lead to theories being mistakenly interpreted and applied and can be damaging to students by forming a deterministic view which makes understanding genetic interactions in the present genomics age harder (Lewis, 2011).

Previous attempts at limiting genetic determinism in education have been made, although ultimately have been limited by the lack of interest and time, workload to find resources and develop a syllabus, and the 'conservative' nature of textbook publishers (Redfield, 2012). I will discuss my original findings from personal email interviews with two biological educators who aimed to reform the curriculum in the 1970s and 1980s, and examination of their textbooks. From these cases, I conclude how semantic changes which emphasise Mendel's laws as special occurrences, removing Mendel from the focus of chapters on genetics and including, even if brief, some historical context in which the discipline of genetics grew, can result in a less deterministic explanation of the genetics portrayed. I will also highlight the social factors which influence the curriculum by demonstrating why these reform efforts were largely unsuccessful, and thus undermining the common misconception that textbooks are neutral presentations of scientific *facts*.

2 History of Genetics Textbooks

When used in education, textbooks have a universal status as politically neutral, cohesive presentations of research (Issitt, 2004). Yet in reality, they are product of the time and culture they developed in. This is revealed by Castéra et al. (2008) who analysed expressions relating to a 'genetic program' in fifty biology textbooks, across sixteen countries. They found these were absent from Eastern European countries and Germany and suggest it to be due to the influence of Lysenko during the Soviet period who opposed a form of Mendelian heredity, and the reactions against the Nazi period, respectively. They also noted recent absences of the expressions and implicit values in Tunisia, due to the increase in educational research. The study demonstrates how textbooks are used to convey implicit messages related to certain values, and are not 'passive representations of a science that exists elsewhere', or 'artifacts', but '*interpretations*' (Skopek, 2008, p. 2). Skopek convincingly discusses how writing shapes scientific developments, making history not just a frame in which scientific claims can be removed from, but a part of their production (Skopek, 2011). This is significant for textbooks, where statements are assumed to be accurate and well-established.

[3] Weldon recognised the oversimplification of Mendel's results, that peas were not either wrinkled *or* smooth, yellow *or* green, but displayed continuous variation dependent upon the interaction of heritable genes, as well as environmental conditions (Radick, 2015). Weldon was a biometrician, and used Pearson's method of statistical analysis to highlight how Mendel's data fit his theory too well (Weldon, 1902b). While Weldon's argument had little impact, Ronald A. Fisher (1936) published a notable paper which closely examined Mendel's evidence. Although admiring his experiments, Fisher concluded that Mendel's results were too close to the expected ratios and must be questioned.

However, during their production, the personal preference of authors dictates the inclusion of certain theories and methods over others. Being presented in a textbook is how a fact is formed, as it 'becomes a definite through constraint' (Fleck, 1979, p. 121). As a result, textbooks are 'the conclusion of a process of accreditation' (Skopek, 2008, p. 5). This means the science presented in genetics textbooks is not necessarily the most accurate, but the culmination of a centuries-worth of scientist's intentions and biases. By accepting textbooks at face value, Kuhn (1970) discussed their role in establishing paradigms within the scientific community, and therefore also dictating the direction of scientific inquiry. Consequently, it is important to recognise the context in which genetics textbooks developed, for students to gain a more objective conception of science. Additionally, the fact that textbooks remain the framework for teaching practice in the classroom means their analysis can indicate the values and purposes represented in schooling (Goodson, 1989, p. 134).

Rose explained how 'you cannot divorce "science" from the society in which scientists are embedded and whose concerns and interests the science we/they do reflect'.[4] With many possible descriptions of living phenomena, Rose (2005) argued that theories depend on the purposes for which the explanation is required. Therefore, the mathematical formulae made for animal and plant breeding cannot be applied to phenotypic characters such as human social behaviour, arguing against the use of Mendel's principles today. Heredity became rooted in a variety of biological problems which later developed into different areas of practice such as cytology, embryology, physiology and natural history (Sapp, 1987). Thus, how it was understood depended on the objectives of the discipline, as well as the techniques and theories involved. For example, heredity for embryologists was concerned with 'production and reproduction', whereas for Mendelian investigators, heredity was defined in terms of 'distribution and exchange' (Sapp, 1987, p. 35).

Scientific idealisations are used by scientists to simplify theories and models for explanatory purposes. Whilst useful to describe abstract phenomena, such as genetics before knowledge of genes, it can be misleading as scientists' interpretations align with their own motivations. Varying interpretations of Mendel's research are evident in early textbooks, where three authors, Arthur Thomson (1908), William Castle (1916) and William Bateson (1902), used their genetics textbooks to present the science in accordance with their views, and support different forms of hereditary science. Skopek (2008, p. 26) suggested how the different conceptions of the science 'informed the ways in which they interpreted primary sources and reconstructed the contemporary historiography of their field'. For example, in Thomson (1908) Mendel's genetics was depicted as an interpretation rather than a law, from the perspective that the study of heredity is about understanding the material basis of life and regarded genetic relation as 'germinal similarity' (ibid., p. 29). His was the first full-length textbook in English covering heredity since the rediscovery of Mendel's laws. Despite being influenced by leading Mendelians Bateson and Punnett, Thomson did not ascribe such importance to Mendelism. Castle was similar, viewing Mendel's work as a small step in a longer historical development of ideas, and not anything special. To him, genetics was about the development on an individual or species scale, and ultimately viewed genetics as a science of 'coming into being' (ibid., p. 49). Castle's textbook, *Genetics and Eugenics* (1912), was popular in the USA during the 1930s, revised four times, and heavily influenced students including Leslie Clarence Dunn who wrote the textbook *Principles of Genetics*, widely used during 1930s–1950s. Bateson's genetics, very different to Castle's, was about discovering laws and mathematical order, focussing on Mendel

[4] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

and discrediting other lines of research. He assumed the purpose of Mendel's experiments was to find laws of inheritance which apply to all species (Bowler, 1989). Bateson wrote his textbook towards the end of the decade-long conflict between British Mendelians and biometricians, using the rediscovery of Mendel's experiments to support his own morphological experiments, presenting a discontinuous approach to evolution (Skopek, 2008).

Despite the alternative ways of characterising genetics from the three authors, Bateson's historical approach beginning with Mendel as a heroic figure and his laws became the disciplinary frame in genetics textbooks. Bateson's *Mendel's Principles of Heredity* (1902) was standardised throughout the first three decades of the twentieth century and Skopek indicates that by the 1930s, there were few textbooks that did *not* treat Mendelism as the foundation of the science (2008, p. 121). As authors present the authority of different historical figures and theories as fundamental dependent on their own judgement, students learn an interpretive framework through textbooks. A neat analogy described textbooks as 'built up from individual contributions through selection and orderly arrangement like a mosaic from many coloured stones' (Fleck, 1979, p. 119). They do not present pure objective science, but are compilations of theories influenced by choice. As textbooks help to shape the resulting science, they are a useful source to analyse the features in the history of textbook production during the 1900s which may have led to how genetics is taught today. Features which have promoted genetic determinism include the oversimplification of heredity, and the use of problem-solving exercises.

Condensing patterns of inheritance into textbooks helps students grasp the principles of heredity. Beginning with simplified models builds a foundation of genetic literacy within the time constraints of teaching, but can have negative implications for the learning outcomes of students. In fact, oversimplification does 'more harm than good' by exaggerating the determinative power of genes, and excluding essential contextual factors (Jamieson & Radick, 2013, p. 578). The concern is that the presentation of Mendelian patterns as laws implies a simple, universal impression of inheritance. Such simplifications may be understood as realistically depicting the whole complex phenomena. Moss (2003) distinguished between *gene-P*, a concept of the gene as determining the phenotype, and *gene-D* which recognises the gene as a developmental resource. *Gene-P* is a useful model in medical genetics to predict phenotypes without full knowledge of the gene, or described by dos Santos, Joaquim and El-Hani as 'instrumental fiction' (2021, p. 552). The concept of *gene-P* is also useful for teachers to explain genetics in simplified terms. However, by omitting the insight to the nature and role of the model used, the context in which *gene-P* is useful and addressing the more realist concept of *gene-D*, the teacher and student are led to a fixed idea of inheritance. This can favour genetic determinism if students believe there are 'genes for' all phenotypic traits, with no other epigenetic or environmental factors involved (Allchin, 2003; Lewis, 2011; Smith & Gericke, 2013).

I have experienced this as a practicing teacher, hearing children discuss having genes for complex characteristics such as being ticklish, or angry. Additionally, an area which has been oversimplified in textbooks is the recognition of contributing scientists. Only scientists who shared Bateson's ideology, such as Galton, Weismann and De Vries, are shown to contribute to the growth of genetics. Including certain aspects of their research adds further bias to the early representation of heredity. For example, Weismann is reported to have helped simplify investigations of genetic problems and challenged followers of the theory of inheritance by acquired characteristics to provide evidence. Yet his well-recognised theory of germplasm and hereditary determinants was ignored in Bateson's presentation of heredity (Skopek, 2008, p. 44).

Another feature which impacts the scientific content delivered by textbooks is the use of problem-solving, introduced in the 1920s as a way for students to use data in their own discoveries in creating a 'virtual historical environment' (Skopek, 2008). Repeatedly using diagrams, figures and oversimplified methods of finding a solution cements Bateson's ideology, bringing a system of rules together as cases of acceptable agreement to help predict the outcome of phenotypic ratios. Bateson's version of Mendel's experiments, thus that which has dominated the British curriculum, emphasised a systematic experimental approach. It presented the links between the experimental data and observed ratios 'obvious', leading to discovery of the laws of segregation and independent assortment (Skopek, 2008, p. 41). Bateson believed these ratios demonstrated 'the operation of a universal orderly system' (ibid., p. 42) which, despite the recent discoveries of variability and complexity, is still evident today.

By removing the intricacies of Mendel's experiments, students are led to believe data which has been selectively chosen from true breeding organisms (for the laws to function) will *always* align with given ideal ratios, rather than in *specific* circumstances. Including certain illustrations for predicting outcomes of crosses whilst discounting other methods fits with goals of the authors (Skopek, 2011). For example, textbooks and the curriculum widely employ the Punnett square to determine the outcome of two individuals with known genotypes. Use of this suggests genes are isolated and always act in the same dominant-recessive pattern, encouraging a deterministic view. dos Santos et al. (2012) found the most prevalent gene concept presented in Brazilian biology textbooks was a version of fixed *gene-P*, and suggested this was due to the use of these predictive tasks embedding the idea that genes determine traits. A less popular technique is the pedigree map used by Sturtevant and Beadle (1939) where algebra is used to calculate the outcome of multi-gene crosses. A comparative study with disciplines such as zoology and botany found problem-solving techniques were unique to genetics, indicating that the use of these in textbooks contributed to the formation of genetics as a discipline (Skopek, 2008, pp. 95–101).

The rewriting of textbooks has formed Mendelian genetics as we know it. Mendel has become part of the common culture of genetics due to factors which led to promoting Mendel's laws, while overlooking his opponents'. Textbooks adapt principles by presenting them using a model of scientific ideals, suggesting how science should be carried out, and using problem-solving exercises to reinforce this. Instead, it seems more important to accurately depict the science as it developed, and present science as a 'social activity', rather than a 'mechanical process for generating facts' (Bowler, 1989, p. 8). For example, including the Mendel-Fisher controversy in which Fisher suggested Mendel may have exaggerated his results would demonstrate that disagreements exist in science and 'science is not merely a set of "facts" to be memorised' (Smith & Gericke, 2013, p. 153). Textbooks present a false story and recreate Mendel 'to fill a monumental, heroic image', accounting him for more than he did (Allchin, 2003, p. 333). Exploring the other notions of heredity which formed at the beginning of the twentieth century would add value to students' learning by showing the influence of social, cultural and political factors. Discussing the developments since would show the nature of science as progressive, where research is often mistaken, challenged and revised. Science is not the result of individual discoveries but a collective accumulation, influenced by the context in which they developed. Therefore, the theories in textbooks must be understood within the framework that they were produced. Textbooks should present Mendel's work as well as a 'wider view of the actual history and a depiction of science as a social process' (Kampourakis, 2010). Two attempts which have recognised the importance of contextualising the genetics in textbooks include Steven Rose's parallel text exploring the development of genetics throughout the 1900s, and Garland Allen's changes in language and organisation to move Mendel from a figure of authority to a figure in history.

3 The Challenge of Suiting the Preference of All Those Involved

3.1 Steven Rose

The first attempt at reducing the emphasis on Mendel in the genetics curriculum analysed in this study was from Professor Steven Rose. Born in 1938, he gained a double first degree in biochemistry from Cambridge University and a PhD at the London Institute of Psychiatry. With a background of working in the biochemistry department at Oxford University and on the Medical Research Council at Imperial College in London, he was one of the first professors at the newly formed Open University (OU) in 1969. It was here that he became responsible for creating a new biology syllabus for distance learning, as well as forming a new department and his own Brain and Behaviour Research Group (Stevenroseonline.net, 2019). Throughout Rose's career, he demonstrated concern over the ethical, legal and social implications of scientific developments. With collaborator and wife, Professor Emerita of Social Policy Hilary Rose, he wrote the successful book *Science and Society*, and created the British Society for Social Responsibility in Science.

Rose wrote the book *Lifelines* arguing humans are the product of the 'social' as well as the 'biological', and that we have lifelines which depend on our history as well as our molecular constituents. These lifelines change over time due to many 'interacting variables' (Rose, 2005, p. 79). Through his developmental studies, Rose suggested each cell has an identical set of genes, yet their expression depends on the genes' development within that particular cell. Rose praised Mendel as the pioneer of a 'seemingly straightforward' genetics, but highlighted how the ratios 'only appear in particular instances' and that 'gene expression varies in both time and space' (ibid., p. 101). Rose strongly advocates that the advancements in our understanding of genetics since the 1900s must be reflected in the genetics textbooks. He expresses concern of genetic determinism resulting from the oversimplified version of genetics based on Mendel's principles. In *Lifelines*, Rose discussed how presenting a direct causal relationship between genes and behaviour results in neurogenetic determinism in which people may claim to have genes 'for' traits such as homosexuality, alcoholism and criminality. This leads to wrongly 'blaming the victim', directing the attention and funding away from the social and economic problems the individual faces. He stated 'people may be gay or violent or schizophrenic or selfish, but brains or genes cannot be' (ibid., pp. 296–305). Motivated by wanting to avoid this, Rose aimed to provide a more honest genetics education. This involved highlighting the social and historical factors which led to the propagation of a simplified, outdated and potentially misleading understanding of heredity.

3.2 Origins and Purpose of the OU's New Genetics Course

Rose was tasked with creating a new biology syllabus for distance learning at the OU. Whereas genetics today is central to almost every area of biology, it was scarcely taught in universities 50 years ago as few institutions were large enough to fund, direct and teach a full genetics course.[5] Rose's aim was to promote teaching products which could be used regardless of the genetic skills across different staff and universities. Rose ran the production of the course which involved a 3-year collaboration between the biology departments

[5] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

at OU, Birmingham, Hull, Sussex and York universities. At the time, there was a significant drive for increased genetics understanding and research. Plant breeding centres were rapidly growing and much of public investment was in agricultural research. Due to technical changes and genetic improvements, the productivity of British farmers is claimed to have doubled between the 1950s and 1990s (Palladino, 1996). A scientifically literate society was needed to support advancements in research, and thus, the development of a genetics course was funded by the Nuffield Foundation, aiming to promote inter-university teaching projects and develop the type of structured teaching that the OU had refined. The resulting course (S299 – Genetics) entailed 12 h per fortnight, and covered a set of sixteen units from classical to population and human genetics. It included an accompanying television and radio programme and incorporated a series of home experiments.

The course ran in a linear sequence with the first unit asking the question 'What is Genetics?', which covered Mendel and his experiments with peas. The remaining units comprised chromosomes, genes, recombination and linkage, molecular and developmental genetics, population analysis of plant and animal breeding, and crucially ended with two units on controversial issues surrounding human genetics (Rose, 1976). Rose writes how he was 'uneasy' about the genetics course beginning with Mendel, and claims the issue was trying to teach the main concepts in genetics alongside its 'unsavoury history'.[6] This is evident in his textbook, where I note that whilst Rose followed the standard form of starting with Mendel, he was quick to raise questions about the social interactions of genetics and one of the five objectives of the unit was for students to 'cite 3 examples of an interaction between genetics and society', withholding the importance of contextualising science. The textbook features disclaimers throughout, maintaining Rose's desire to address the history of genetics and avoid teaching it as pure. Specific examples are used to discuss questions raised by genetics, such as a court case in which the theories help determine the relationship of a son to the father. It states: 'The contributions genetics made to the paternity case enabled conclusions to be reached with a well-defined probability, but not absolute certainty' (The Open University, 1976a, p. 5). This is followed with the comment that:

> Genetics has helped, in some instances, to clarify the rules of biological inheritance and to replace bigotry by biology. However, do not be misled into thinking that genetics, which after all represents the thinking of geneticists, has developed over the last 100 years free of prejudice…Just as genetics has influenced our thinking and everyday lives in areas such as animal breeding, crop production and medicine, and promises (or threatens) to influence also social welfare and education policies, so genetics itself has been influenced by social mores and prejudices…these interactions between genetics and society will become apparent during this Course. (The Open University, 1976a, pp. 6–10)

Another use of a case study highlights the different questions which are seen as important by particular groups of geneticists. With sickle cell anaemia, for example, the classical geneticist asks 'what degree are traits biologically inherited?', whereas the molecular geneticist asks 'which physical structures are responsible for inheritance?' and the population and evolutionary geneticist asks about the 'frequency of the trait in a population' (The Open University, 1976a, p. 7). This shows how their intentions influence the approach taken, which is important for students to be aware of as they continue through the rest of the course.

[6] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

Although starting the course with Mendel was unavoidable for Rose, he addressed the 'long and problematic history [of genetics] permeated with eugenics, racism, sexism and classism' and sought to avoid presenting the teaching of genetics as 'pure'.[7] In addition to the questions regarding the context embedded in the units themselves, he wrote a parallel text: *The History and Social Relations of Genetics* (*Hist*) and ended the course with a discussion of the ethical controversies over race, genetics and intelligence (The Open University, 1976b).

3.3 Rose's Parallel Text, 1976

In *Hist*, experiments and theories, such as those of Wesimann, Mendel and Darwin, *Drosophila*, *Neurospora* and bacteriophage, are discussed to highlight the influences of time, types of organism and intentions, together with the social and philosophical repercussions. By placing the developments of genetics featured in the main text within the culture they arose in, *Hist* provides students with a broader and more honest understanding. The aim was for it to be studied in parallel to the units of the main course, and it contains cross-references throughout to guide students to make links. Furthermore, the material in the parallel text formed part of the course assessment. This demonstrates the perceived importance of the historical and social context to the understanding of genetics by Rose, rather than additional knowledge which could be overlooked by students and professors had it not been assessed. Ultimately, as explained in its introduction, '*Hist* is intended to encourage and help you to develop a critical attitude to developments in contemporary genetics, and indeed to our teaching of it' (The Open University, 1976b, p. 6).

The introduction in *Hist* addresses how the content presented in this course, made in the 1970s, would have been very different to that of the 1930s, and later remakes in the 1990s. It explains this to be the result of the 'facts we chose to present or the theories to explain them' as well as 'our entire way of thinking about what were the key questions with which genetics was concerned' (ibid., p. 7). By comparing how the approach as well as the knowledge changed through time, *Hist* highlights how the intellectual framework or paradigm, which the facts and theories of a subject are embedded in, changes. Therefore, to fully understand the development of genetics we must ask which questions were regarded as important at the time. Influential interactions in the growth of the science discussed in *Hist* include the internal factors in the development of genetics, the state of available techniques, the social input and the mix of all of these in determining the social output (The Open University, 1976b, p. 8).

After the introduction, the text unravels the history of genetics in a story-like manner, beginning with Darwin, Mendel and Weismann. While the 'what' of their ideas and experiments is explained in unit 1 of the course's main text, *Hist* describes the 'who' and 'how' they emerged when they did (ibid., p. 10). Then, once having set the scene with the work of predecessors Darwin, Linnaeus, Lamarck, Malthus, Galton and Huxley, *Hist* outlines the experiments of Mendel. It explains how the aim of his work was to identify characters that are constant, and expressed in some but not others of a population. The text questions the neglect of Mendel's work and his intentions for counting and calculating ratios in the way he did (ibid., pp. 14–15). *Hist* continues by discussing the social impact of genetic and evolutionary theories in the nineteenth century, describing the lead up to social Darwinism and eugenics.

[7] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

The next chapter, entitled 'The triumph of Mendelism, 1900–1920', covers the conflict between Darwinians and Mendelians, the lesser discussed integration of continuous variation and Mendelism, the establishment of the chromosome and mutations and the rebirth of population genetics with contributions from mathematicians. The following chapter covers the politicisation of genetics and geneticists, addressing how genetic ideas have been used to support or oppose existing social order (ibid., p. 29). This includes eugenics, immigration and social Darwinism, genetics and the Nazis and Lysenkoism. Having discussed the growth of classical genetics, *Hist* includes a chapter on the rise of molecular genetics, appreciating those such as Ephrussi, Beadle, Morgan, Avery and Schrodinger amongst others, until Crick and Watson, noting all as contributing to understanding the chemical identity of heredity. It highlights how the 'path to the double helix was not a straightforward one' and that there were many 'false trails and many disputes among those who were following it' (ibid., p. 38). Furthermore, it states how 'the right way forward depended on the development of new techniques and the choice of a suitable experimental organism' (ibid., p. 38). The text also notes the distance 'both conceptually and in time' from understanding genetics within the eugenics movement and Lysenkoism, and now (ibid., p. 52). The chapter ultimately emphasises the uncertainty and relativity often involved in scientific investigations. Exploring the history of genetics in this way offers students a full, honest depiction of how genetics developed at the beginning of the twentieth century, with all of its ideological conflicts and their impact. This allows students to understand how scientific advances depend on the society at the time, rather than believing what is presented in their textbooks as the only possible interpretation, or an 'objective scientific truth' (ibid., p. 52).

The final chapter entitled 'Has molecular biology defused genetics?' allows students to use the conceptual framework provided, to set and answer questions. It raises some of the uncertainties which remain, encouraging students to think beyond the detailed history, and the social consequences of modern genetics. Philosophical discussions over the classical hypotheses of genetic variation are used to highlight the 'common myth' that scientists collect evidence, before using logic and intuition to interpret them. *Hist* provides a chronological table outlining the flow of events leading up to the present understanding of genetics. This is a concise way of representing the advances in genetics, whilst also explicitly stating that the list does not mean that one event caused another.

3.4 Responses to Rose's Course

The demand on students to engage with increasingly complex explanations of genetics as well as the inclusion of the nature and history of developments provoked discussion and the *Nature* articles from 1976 expose issues with creating a new genetics curriculum. Specifically, the Edinburgh biochemist Henrik Kacser and colleagues argued a generous opportunity from the Nuffield Foundation had been wasted. They complained about the content of the course exceeding the time allowance for a second year module, suggesting that students would need more support from the OU as the 'length and depth of the course was thought to be far beyond the capacities of the intended students' (Kacser et al., 1976). The article discussed how the rest of the Consultative committee for the course claimed to have suggested offering two half-courses, but Rose rejected any changes.[8] He is thought to

[8] It should be noted that this consultative committee is made up of the 3 authors of this contentious article (Professor J. Sang, R. H. Pritchard and Dr. H. Kacser), amongst others including Professor W. Bodmer, J. Jinks and D. Jones, members of the OU course team, and Professor D. Lewis as chairman. This could mean the article is particularly insightful or alternatively biased.

have ignored advice from the committee that the course should not be published without amendment.

In response, Professor Mike Pentz, the director of studies at the OU, claimed that all units were independently tested with students. He reported results from running the course where 99% of students taking unit 1 said it was 'okay to very interesting' and 98% of students said it was 'okay to very easy' to understand. Similarly, 78% of the students studying unit 2 gave these answers to both questions covering interest and difficulty. This demonstrates how the workload was viewed to be normal for OU courses, and Pentz argued the committee never considered the timings of the unit to be an 'impossible task'. Pentz also defended that all decisions were made not just by Rose but by the whole team, and that other institutions planned to use parts of the course in their teaching, claiming it a success (Pentz, 1976). Further correspondence reinforced opposing ideas that the course was 'too long, too advanced, and too detailed for second level part-time students and was inadequately prepared for non-OU institutions', suggesting a loss of money and time (Sang et al., 1976).

This illustrates difficulties with developing a new or modified genetics curriculum. Even Rose's course, which generally followed the standard presentation of Mendelian genetics but with an additional supplement to place the science in context, was criticised as too much work for the students. It demonstrates the tension between depicting an accurate presentation of scientific developments and the need to simplify scientific theories for the learning of students. Rose holds that the course was no more challenging than other science courses being made at the time, but believes that with the 'changing student population and cuts in funding, courses in general are much lighter than they were in the early days'.[9] Furthermore, the time needed to develop a genetics curriculum was an issue and Rose, when asked if he made any further changes in response to these criticisms, said his research group was occupying more of his time and thus could not be involved in later remakes.

3.5 The Revised Version of the Course

The S299 course led by Rose ran for 8 years before being revised, the standard amount of time for OU science courses at the time.[10] Table 1 shows a general outline of the original and revised courses. The organisation *and* focus appears to have changed in its remake, as well as a general reduction in content. S299 aimed to distinguish the three approaches to genetics, featuring classical genetics in units 2–5, molecular genetics in units 6–8 and population genetics in units 9–13. It states how 'these divisions are not arbitrary; they reflect, as unit 1 shows, different types of question about one particular problem' as they 'define the sorts of answers available to the biologist attempting to explain a particular phenomenon' (The Open University, 1976b, p. 9). It later states that 'having set our framework for the emergence of population, molecular and formal genetics in the nineteenth century, we can now move on to see how they have interacted and developed since' (ibid., p. 18). As previously discussed, this demonstrates Rose's attempt to show how scientific theories depend on the investigator's intentions, from a background as a scientist, author and cofounder of the British Society for Social Responsibility in Science. The text features extracts and pictures, and presents itself more like a story of the development of genetics

[9] Pers. Comm., Steven Rose to myself (email), 25 Apr. 2021).

[10] Pers. Comm., Steven Rose to myself (email), 25 Apr. 2021).

Table 1 A comparison of the content of Rose's course, S299, and the revised course, S298

S299 (The Open University, 1976a, 1976b)	**S298** (The Open University, 1987)
1. What is genetics?	1. The process of heredity
2. Chromosomes and genes	2. DNA and heredity
3 and 4. Linkage, recombination and maps	3. Mutation, cell division and chromosomes
5. Chromosomes: organisation and changes	4. The transmission genetics of eukaryotes
6. Molecular genetics	5. Gene transfer in bacteria and bacteriophage
7. Cytoplasmic inheritance	6. Gene structure and function
8. Developmental genetics	7. Regulation of gene expression in bacteria and viruses
9 and 10. Analysis of populations	8. Regulation of gene expression in eukaryotes
11. Biometrical genetics	9. Genetic programs and development
12. Theories of plant and animal breeding	10. Genes and morphogenesis
13. Ecological and evolutionary genetics	11 and 12. Genes in populations
14 and 15. Human genetics	13 and 14. Biometrical genetics and plant breeding
Statistics for genetics	15. Human genetics
The history and social relations of genetics	Techniques and exercises in molecular genetics

in the nineteenth century, including a very detailed history of Mendel and the conflict with Bateson.

In contrast, the revised S298 course was not organised by approaches to heredity, but focused instead on the *mechanisms* of heredity. The parallel text in the revised course was designed to 'dip into' during the course, and the cross-references were compiled to 'relate the historical context of genetic ideas to their place in today's understanding of the subject' (The Open University, 1987, p. 3). The parallel text was no longer assessed as it was in the original course, leaving the only formal reference to the historical or social context of genetics to that included in units 14 and 15 ('Human genetics'). This is an example of how the reduction in content due to workload and time constraints belittled the importance of situating knowledge of genetics in context. The parallel text states how this genetics course is about 'four main things': heredity, inheritance, development and the environment, and acknowledges that the presentation of genetic concepts in the main text is as if 'they were obviously true and have been true at all times and all places' (ibid., p. 3). The course begins with DNA, and then genes, followed by genes in different organisms, before their application to humans. One of the leading editors of the revised course, mathematician Brian Goodwin, was a key founder of theoretical biology which uses mathematical methods and physics to understand processes in biology (Swarz, 2009). Other key editors of the revised course include Alistair Ewing who specialised in gene structure and function and David Sherratt, a molecular biologist.

Owing to various backgrounds and interests, the authors had different approaches and priorities when presenting genetics in textbooks. The original course proposed by Rose emphasised the context in which the discoveries were made and the impact they had, but the later course run by theoretical and molecular biologists promoted an increased focus on the mechanisms of genes, demonstrating how the authors dictate the science conveyed. Major sections on race and intelligence which featured in Rose's course were removed in the remake. This included 'genetics and the concept of race', examining the theories and evidence used to support claims for genes of intelligence across different racial and class groups (The Open University, 1976a, pp. 657–659). Analysing evidence would be

important for students, to develop critical skills and apply science to the world around them, and excluding this opportunity may limit scientific literacy.

3.6 Looking Back

Since the S299 course was first proposed by Rose and others, the content in subsequent versions has been reduced. Evident from visiting the archives of the course at the Open University, the next version of the course, S298 Genetics, featured a parallel text but covered less material, and much of which was removed and the social and historical context was prioritised by Rose. The accompanying video modules go from a count of sixteen 24-min episodes in S299 to eleven episodes of the same length in S298, and audio modules reduce from sixteen 18-min episodes to nine. As well as the loss of content, the focus changed between the two courses, from covering a range of areas in the earlier course such as the 'past present and future', mutations, flies, evolution, genetic engineering, Lysenko, genetic counselling and 'genetics and society' to a noticeable loss of historical and social context and more focus on patterns, statistics and engineering in the later course.[11] Despite this, and the controversy in *Nature*, the parallel text features in the remake, implying Rose's aim to include the social and historical context had an impact.

Rose maintains that if he was to propose a new genetics course again, he would try *not* starting with Mendel. He argues that the study of classical genetics should be limited to historical interest, and that a better course would focus on the progress made in the last two decades, covering developments in the Human Genome Project, gene editing, population genetics and epigenetics. Even the most recent genetics course at the OU, 'Science: human genetics and health issues', does not address this. Compared to earlier courses, the current course places higher emphasis on the issues surrounding genetics although strict, prescriptive patterns of inheritance of genes and how they function to cause disease remain the focus ("SKG095 | Science: Human Genetics and Health Issues", 2021). Rose advocates the inclusion of history, social relations and ethics.[12] This highlights a continued motivation for a course where recent developments are the focus and Mendel is only a part of the *history* of genetics. Rose describes how the content of courses had to be reduced since the 1980s, to match the decreasing motivation amongst students.[13] Whilst a generalisation, this may explain the exclusion of the parallel text as part of the examination. Ultimately, Rose's case demonstrates the practical challenges of time and workload for those modifying a course, as well as the presentation of science in a way which suits the students. Curriculum reform depends on the participation of many individuals, from stakeholders such as teachers, parents and politicians to experts in science and pedagogy and collective entities such as the ministry of education and local authorities (OECD Education Working Papers, 2020). The controversy described in *Nature* demonstrates the difficulty in achieving agreement amongst all the parties involved: committees, foundations, other research scientists, university professors and the students themselves.

[11] Own comparisons made between the Open University digital and paper archives for each course. For S299, see https://www.open.ac.uk/library/digital-archive/module/xcri:S299/program and for S298, see: https://www.open.ac.uk/library/digital-archive/module/xcri:S298/program. Later courses offered by the OU relating to genetics, in chronological order are: S195 Introduction to the human genome, SK195 Human genetics and health issues and SKG095 Science: human genetics and health issues.

[12] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

[13] Pers. Comm., Steven Rose to myself (email), 21 Apr. 2020).

4 The Impact of Small Semantic Changes

4.1 Introduction to Allen

The next attempt to revise the genetics curriculum in this study is from Garland Allen, winner of the most prestigious award given by the History of Science Society: the Sarton Medal. Born in 1936, the American historian and biographer integrates science in society, having taught as a biology teacher at many schools and universities. Allen believes we cannot write the history of biological ideas *without* including their development as part of a broader economic and social context, and is known for writing the 'first genuine history of modern biology': *Science in the twentieth century* (1975), addressing the gap between science and its history (Churchill, 1976). His particular research interests are in the area of history and philosophy of biology, and the relationship between genetics, embryology and evolution between 1880 and 1950 (Biology, 2022). Allen contributed an article on 'Biological Determinism' to the *Encyclopedia of Disability*, and is currently co-authoring a chapter about the failed attempts to find genetic differences in human race, demonstrating his concern over teaching a deterministic genetics course (Albrecht, 2006). Allen has contributed to many biology textbooks, notably *The Study of Biology* with Jeffrey Baker, written as an introductory book for a two-semester course. As the book was revised through its four editions, Allen attempted proposing a change to the teaching of genetics, recognising the determinism of Mendelian genetics and the need to include the social and historical context. Ultimately, the publishers rejected any major changes.

4.2 Nature of the Problem

Allen's extensive research on the work of Thomas Hunt Morgan and others in the 1930s revealed most hereditary patterns were exceptions to Mendel's oversimplified one gene, one trait approach (Allen, 1978). Concerns over the simplistic application of Mendel's work to eugenic matters, alongside Allen's exploration of agricultural genetic literature, heightened his issue with Mendelian genetics failing to apply to much of the breeding data researchers had collected. Why then are Mendel's ratios still the foundation of a universal teaching of genetics? Allen suggests it was because the rediscovery of Mendel's genetics began the 'twentieth century age of genetics'.[14] Mendel's form of inheritance involves easily identifiable phenotypic traits making it simple to teach, and it is experimental and based on simple statistics, hence easy to understand.

4.3 Changes Proposed and the Problems Faced

The Study of Biology was republished in four editions in 1967, 1971, 1977 and 1982, and led to a variety of versions of the textbook also by Allen including *A Course in Biology*, *The Study of Botany* and *The Process of Biology: Primary Sources* (Adams et al., 1970; Baker & Allen, 1968, 1970). The complications arose when producing the fourth edition of *The Study of Biology* where authors planned to start with molecular genetics, and include Mendel later. Allen wanted to take a historical approach as a result of his own work in the history of genetics, with the underlying theme for each subject as 'Science as a process

[14] Pers. Comm., Garland Allen to myself (email), 27 Nov. 2020.

rather than authoritatively dictated "facts"…' summarised in the simple question: 'How do we know what we know?'[15] To convey this theme, Allen proposed starting with general observations on the discovery of heredity over the past couple of centuries. He wished to include Mendel, but only alongside emphasising that most traits do not follow Mendel's basic scheme. Allen intended to then explore the nature of genes and chromosomes, the work of the Morgan school, T. S Painter and others that contributed to a linear arrangement of genes on chromosomes, leading up to the discovery of DNA and Watson–Crick.

In spite of Allen's logical reorganisation, the publisher argued such a novel presentation of genetics required the teachers to adapt to teaching it this way, and rejected the changes as too much of a challenge. Unfortunately, due to time constraints and the lack of support from the editor, Allen reports they were forced to abandon the intended revisions.

4.4 Solutions

Despite the rejection of larger changes to the textbook, Allen described a few 'smaller' ones.[16] The fourth edition opens with a discussion of the various levels of organisation in the field of genetics including the organismic, cellular, chromosomal and molecular, but most importantly, not with Mendel. Following this is a section on chance and probability, before introducing Mendel alongside the historical context, methods of breeding and mathematical tendencies.

Although Allen recounted not being able to proceed with his original plans, my comparative study of the second and fourth editions demonstrates significant revisions in recognising Mendel as an exception to the principles of inheritance, removing him from the focus and resulting in a less deterministic portrayal of genetics. This was achieved through small semantic changes leading to a change in emphasis, as well as an inclusion of context.

4.5 Comparative Study

Through analysis of chapters relating to genetics in the second and fourth editions of *Study of Biology*, I will discuss how changes to the presentation of genetics and the language used can alter the impression on the reader.

4.5.1 Study of Biology, 2nd edition, 1972 (Baker & Allen, 1972)

The second edition of the textbook encompasses two chapters on genetics: 'Genetics I: From Math to Mendel' and 'Genetics II: From Mendel to Molecule'. The titles of the chapters alone indicate the focus on Mendel with both chapters centred around his version of genetics and mathematical assumptions.

The first chapter opens with binomial expansion and mathematical probability for the inheritance of genetic factors. In many instances, a problem is set up and then answered with Mendel. For example, when discussing fur colour in mice it states that 'the black factor may in some way be stronger than the brown factor', and that Mendelian genetics leads to the 'explanation' of these results. Using the term *stronger* implies that certain genes will always be dominant over others, forming a deterministic view of Genetics. Furthermore,

[15] Pers. Comm., Garland Allen to myself (email), 27 Nov. 2020.

[16] Pers. Comm., Garland Allen to myself (email), 27 Nov. 2020.

when first explaining Mendel's principles, the book states it will 'for simplicity, deal with the characteristic of height', and uses a cross of a pure-breeding tall (TT) by a pure-breeding short (tt). This results in a misleading explanation of height purely as an inherited trait, and one that is controlled by a single gene with two alleles, either tall or short. Students are led to ignore the many other complex interactions between different genes which determine height, as well as the environment. Genetic determinism may also result from the use of height to explain Mendel's law of segregation stating that 'since the F1 generation showed that the T factor is dominant over the recessive t factor, the first three fertilization possibilities will result in tall plants. Only the fourth produces a short plant.' The use of assertive language such as *will* and *only* implies this is a fixed pattern of heredity and there are no other contributing factors or resulting possibilities (Baker & Allen, 1972, pp. 506–510).

The chapter continues by setting up a problem with a ratio that does not appear to conform to the Mendelian 3:1 ratio and then solving it in a way which reinforces Mendel's work. For example, dihybrid inheritance is introduced, by describing the production of four phenotypes of mouse fur colour in a 9:3:3:1 ratio and stating how 'another examination of Mendel's work provides an hypothesis to explain the 9:3:3:1 ratio'. Mendelian genetics is also said to 'provide a ready explanation' for incomplete dominance. The storytelling of Mendel's work, which follows, includes the phrases: 'Mendel had noticed', 'Mendel hypothesized' and 'Mendel found'. He is presented as a hero, and his work is used to explain any given ratios. However, the text omits the fact that the data used was highly selected, and known to produce simple, specific ratios with other interfering factors being ignored. Only one paragraph in the entire chapter mentions non-Mendelian genetics where 'the combination of different genes tends to produce varying degrees of partial or incomplete dominance', and highlights that 'simple inheritance in which only one pair of genes is involved is very much the exception, rather than the rule'. Yet, these statements are not further discussed, which may lead to a view that Mendelian genetics *is* the predominant explanation of heredity. For example, the next page discusses that even if 'blending' of traits is seen in the F1 generation, the F2 generation will 'yield results which contradict the blending hypothesis and support Mendel's particulate one', returning to the idea of Mendel's laws as the ultimate explanation (Baker & Allen, 1972, pp. 511–515).The workings of Mendel's rules are presented as definite and undeniable. By overemphasising his theory of genetics and only briefly noting the forms of inheritance which characterise the inheritance most relevant to humans, the instruction limits key aspects of genetic literacy such as gene expression, variation's role within evolution and ethical discussions around genetic technology (Sparks et al., 2020). The chapter ends with 'How to Solve Genetics Problems', further illustrating Mendel as the 'answer' to all questions of inheritance. It uses the uniformity of the Punnet square and simplified ratios to suggest that genetics can be condensed into straightforward mathematical formulae and solutions.

The second chapter on genetics aims to show 'the applicability of Mendel's hypothesis to more complex inheritance situations', still presenting Mendelian genetics as universal. The text describes a cross between a tall, smooth tomato plant and a dwarf, pubescent tomato plant resulting in a 1:1 ratio amongst progeny to be 'contradicting' Mendel's second law. Yet, the explanation that certain genes must be linked is used to 'impose a strong qualification on Mendel's second law: Genes assort at random if, and only if, they are located on separate chromosomes'. This presents a non-Mendelian pattern of inheritance, such as linkage, as support for Mendelian genetics by further refining his laws. Similarly, a cross between feathered and un-feathered birds results in a 'deviant 15:1 ratio' which needs to be explained by another hypothesis. The use of *deviant* suggests this case, of epistatic inheritance, is an exception to a standard pattern of Mendelian inheritance. In reality, Mendelian

patterns are the exception to the complexity of heredity. The textbook continues to present these ratios as explained by Mendel's findings, stating that 'what seem to be contradictions of the ratios predicted by mendelian genetics are often not contradictions at all' (Baker & Allen, 1972, pp. 525–537). Ultimately, any supposed exception to Mendel's principles of inheritance such as linkage and epistasis is explained through adaptation of his laws. Reformulating Mendel's laws to justify non-Mendelian ratios means rather than explaining all of heredity, it becomes evident how narrow his principles are. Only when the genes are on separate, independently assorting chromosomes, and with no other factors or gene-to-gene interactions affecting their expression, can we apply Mendel's ratios. Advancements in our knowledge of heredity have shown that the laws are applicable to a limited domain of heredity; thus, it is inappropriate to present Mendelian patterns as underpinning all human inheritance.

The impression I had from reading chapters of the second edition of the textbook was that Mendel's laws and experiments could be used to interpret all genetic problems. If students are taught in this way, they are likely to be misled and apply his findings from pure-bred, highly selected peas to all of human heredity, cultivating a fixed deterministic approach.

4.5.2 Study of Biology, 4th edition, 1982 (Baker & Allen, 1982)

The fourth edition of the textbook has four chapters on genetics, namely 'Genetics I: From Math to Mendel', 'Genetics II: Cell Reproduction', 'Genetics III: Genes and Chromosomes' and 'Genetics IV: The Molecular Biology of the Gene'. Despite the organisation not being as Allen proposed, the historical and social context of genetics is included throughout all the chapters, taking the focus beyond Mendel.

In the first chapter on genetics, different levels of organisation are introduced with no mention of Mendel. The principles of probability are explained, similar to the second edition, and application of laws of chance is suggested to have led Mendel to his 'outstanding contributions to the study of heredity'. This is the first mention of Mendel, and as part, rather than the predominant focus. Following this is a sub-chapter: 'The Right Person, the Right Time, the Right Place', highlighting how Mendel was not the start of heredity, nor was he the answer. The section explains how his principles are not applicable to all organisms and traits, as discovered by experimenting with animals of true-bred strains. Contextualising Mendel's principles in this way demonstrates his ratios as applying to specific cases, and not the entirety of inheritance as was expressed in the second edition. The textbook suggests Mendel's hypotheses dominated as his 'original generalization regarding a species of plant has been successfully extrapolated to a species of animals', emphasising the move from peas to more complex organisms such as true-bred mice and later humans.

Some discussion of human heredity in the chapter could lead to deterministic attitudes due to the explicit dominant-recessive interactions, for example, brachydactyly, a condition resulting from the inheritance of the dominant trait or albinism, the inheritance of low melanin levels. However, a pedigree chart in which two of three children are albinos demonstrates 'almost the opposite of what we would predict on the Mendelian hypothesis' (Fig. 16.9). This highlights how Mendelian ratios can only *predict* the ratios when large numbers of offspring are involved. It reiterates that Mendelian genetics is formed of 'statistical expectations based only on probabilities' (Baker & Allen, 1982, pp. 446–452). The underlying objective of the chapter appears to suggest Mendelian ratios are one of many possibilities and can only predict the outcome of progeny when on a large scale, or looking at certain traits and organisms. This differs from the second edition of the textbook where anything that does not correspond to Mendel's ratios are presented to be an exception.

The chapter covers complex interactions, including multiple alleles, epistasis and polygenic inheritance to emphasise interaction, non-discrete and non-independent genes. Whilst similar to the second edition by explaining these concepts in terms of Mendel, examples are used to describe the concepts in detail, reducing chances of misleading oversimplification. The use of additional textboxes throughout the chapter introduce some context. For example, although epistasis is described as 'an exception to the 9:3:3:1 ratio', where *exception* implies an unnatural occurrence, there is an accompanying textbox in which it states: 'The existence of epistasis, modifiers, and multiple alleles indicates that genes do not function as isolated units…no phenotypic character is produced by a single gene, but by an interaction of many of the genes in the organism and with factors in the environment' (Baker & Allen, 1982, pp. 462–63). This emphasises the complexity of inheritance, beyond Mendel's one or two trait patterns. Furthermore, whilst height was used as an example of dihybrid inheritance in the second edition, it represents a polygenic system in the fourth edition, due to the continuous variation seen in phenotypes. This stresses the complexity of inheritance through many interacting factors, rather than just the one.

The most significant reference to the nature of science is through a supplementary textbox entitled 'Were Mendel's results too good?', featuring the controversial establishment of Mendelian genetics. By explaining Fisher's paper questioning whether Mendel manipulated his results to align with his expectations, students are encouraged to speculate the science previously presented in textbooks as fact. After his statistical analysis, Fisher proposed that the deviation from the expected ratios should be more than it was, implying Mendel was dishonest (Fisher, 1936). The supplement reports how the close alignment of Mendel's findings to his expectations was due to the 'subjective elements involved in hypothesis formulation and justification', as well as Mendel's selection of pea strains to test, and the data he chose to present. Recognising Mendel's subjective judgement and potential bias leads students to consider the factors influencing scientific research, helping them appreciate that the data presented is not raw nor unselected. The supplement ends with the concluding statement: 'Science is not, nor can it be, entirely free from subjectivity' (Baker & Allen, 1982, pp. 455–456). The use of supplements in this way emphasises the historical and social context in which science has developed, and in the case of genetics, questions Mendel as the fundamental authority. These changes to the use of language, the examples and the context given in the textbook serve to reduce determinism amongst students as they learn to challenge the formation and application of Mendelian genetics.

The first chapter finishes with predicting phenotypes and genotypes of plant and animal progeny, as well as genetic prognosis in humans. The text promotes the use of Punnett squares to solve genetics problems, which are often associated with oversimplifying mechanisms of heredity. For example, it works through an example to find the chances of affected offspring from two carriers for Tay-Sachs disease (Baker & Allen, 1982, pp. 466–467). However, the aspect of chance and probability is emphasised more than in the second edition, important in avoiding the presentation of inheritance as fixed. Genetic problems like these create a 'virtual historical environment' where students can apply Mendel's laws to specific examples, helping them internalise the principles (Skopek, 2008, p. 66). Skopek argued such problems are crucial to the teaching of genetics and unmodifiable by the author. Furthermore, applying the principles to genetic problems is the prevailing way to examine student's understanding. Therefore, teachers focus on these to help students pass exams according to the curriculum, rather than discussing the viability of Mendel's results. By focusing on numerical questions with a right or wrong answer, genetics loses much of its complexity, encouraging a deterministic approach to heredity.

The next chapter addresses reasons for the neglect of Mendel's work when originally published, and reports that only with the help of cytologists, who studied the nucleus and chromosomes, could the missing elements of Mendel's work be explained. Again, this progresses from Mendel as the ultimate focus. It writes how 'his hypothesis…was highly predictive in a number of cases', 'as time went on, an increasing number of expectations to Mendel's basic laws began to appear' and 'ultimately, Mendel's hypothesis raised as many questions as it answered' (Baker & Allen, 1982, p. 470). These sentences denote the uncertainty of Mendel's results, which could lead students to refrain from accepting his principles as universal *laws*. This together with the following chapters discusses the relation of genetics to other levels of organisation including the life cycle, cell division, the discovery of chromosomes and linkage using the fruit fly, chromosome mapping and chromosomal disorders. The increased size of chapters on genetics may reflect the increased knowledge as subsequent editions of the textbooks were produced, in addition to Allen's aim to focus on complex interactions beyond the simple Mendelian patterns of inheritance.

4.6 Looking Back

Allen states that although the adjusted organisation of the four chapters generally worked better, it followed the standard order of presentation and was not what he wished for. However, he was pleased that the content of the chapters focussed on the methods of reasoning and interpretation of data, more than most textbooks. My comparative study demonstrates how this was achieved through including both the scientific context and critical evaluation. The second edition portrays Mendel's laws as the solution to any genetics problem, and anything not following his acclaimed ratios is treated as an exception. The fourth edition successfully contextualises the development of Mendel's genetics to demonstrate that Mendelian ratios are in fact produced by highly selected examples discovered through true breeding plants. Looking back, Allen reports a desire to have pursued the adjusted order of presentation despite the publisher's concerns, implying that he was not convinced by the limited changes he was able to make.[17]

5 Curriculum Reform

Research into social factors influencing the curriculum is limited. Goodson suggested that this is because schools accept the curriculum as a 'given, an inevitable and essentially unimportant variable'. It is regarded as a practical guide to teaching, with little question into the certainty of facts presented. However, the formation of the curriculum is complex due to being 'defined, redefined and negotiated at a number of levels and in a number of areas', and Goodson claims the final product is largely inconclusive (1989, p. 131). This supports my findings from Rose's and Allen's cases that the many parties involved, from students to teachers to national authorities, result in a conflict of interests. Debates over curricula are due to differing opinions on what education is for, and whose knowledge is of most worth (Macdonald, 2003). Often this is too focussed on suiting lesson structure and assessments, and overlooks the effect it has on the students.

[17] Pers. Comm., Garland Allen to myself (email), 27 Nov. 2020.

There is a tendency to assume that curriculum reform of genetics is new, yet previous, albeit few and frequently unsuccessful, attempts have been made. 1940s Russia saw the ministry of education seek change in the curriculum to focus on Lysenko, over Mendel. By 1957, Mendelism was removed from all textbooks, before its reintroduction in 1966 as part of a new biology curriculum. Failure to reform the curriculum was due to the challenges of textbook distribution, the time available to rewrite biology texts and the refusal of parents to buy new textbooks (Peacock, 2013). A more recent attempt was Professor Gregory Radick's, Dr. Jenny Lewis' and Dr Annie Jamieson's endeavour to focus the University genetics curriculum on Weldon, emphasising environmental context and developmental processes. The result was a less deterministic view amongst students and a more 'real life experience of genetics' (Jamieson & Radick, 2013, p. 1284). However, it was ineffective on a larger scale due to time needed to reorganise the whole curriculum as well as the course's demanding expectations of the students, similar to Rose's experience.

5.1 Preliminary Lessons from Rose's and Allen's Reform Efforts

Both Steven Rose and Garland Allen sought to avoid deterministic attitudes being sustained by the genetics curriculum. Rose achieved this through a parallel text which related genetic ideas to their place in the development of the discipline, and focussed on how *and* why certain theories have progressed. Information from the parallel text was assessed as part of the course, demanding genetics to be studied in relation to its history, rather than just as a supplement in the revised version. Allen reorganised the chapters on genetics to not start with Mendel, instead looking at the various levels of organisation in the field of genetics. He incorporated textboxes throughout, which discussed the historical context and critical analysis of results. Furthermore, Allen expressed his non-deterministic intentions for the revised textbook through the careful use of words and phrasing. The language used in textbooks is important, and a recent study by Flodin (2009) has examined its use in textbooks. Flodin discovered that confusion is generated by an inconsistent presentation of the concept of the gene. Despite stating the differences in definitions between a gene as a trait, a regulator or a marker amongst others, authors wish to assert a particular meaning of the gene concept, dependent on their approach. Allen deliberately incorporated less definite language to assert his ideology of genetics as complex and indeterminate.

Although both professors faced challenges in changing the curriculum and were not able to alter as much as intended, I have suggested that they were successful at portraying a less deterministic perspective of heredity. As Rose's course moved away from the standard composure of genetics courses at the time, it led to much controversy. The course was discontinued after a standard duration at the OU, yet the reduction of content to suit work demands meant much of Rose's focus on contextualising genetics was removed. Consequently, Allen's more modest changes appear to have had greater success in correcting the genetics curriculum. The small-scale changes to Allen and Baker's *The Study of Biology* created a different overall impression, with less emphasis on Mendel's *laws* and more on the probability and variation involved in heredity. Allen reported his minor changes to have felt like a defeat.[18] However, in practice they may have had more impact by only slightly adjusting the content of the textbook, rather than the larger changes originally proposed which were more likely to have been rejected by other parties after publication.

[18] Pers. Comm., Garland Allen to myself (email), 27 Nov. 2020.

5.2 The Role of Teachers

Curriculum reform has historically been addressed from a 'top-down' approach where success is measured by adherence to the changes by teachers. More recently, it has been noted that this instead needs to be looked at from a 'bottom-up' approach in which teachers are central to the reform process (OECD Education Working Papers, 2020).

The factors in schools which may hinder or facilitate curriculum reform have been investigated by a study in Hong Kong. Based on questionnaires and interviews, they concluded that the main challenges to reforming the curriculum were the universally 'common' obstacles including the teachers' heavy workloads, the diversity of learning needs and, importantly, the 'inadequate understanding of the reform' (Cheung and Man Wong, 2012, p. 50).[19] The tight timeframe of implementation of reform in this study is thought to have undermined its effectiveness, and results may vary between different education systems. However, a recent review found similar patterns across several countries engaged in reform including Estonia, Finland, Japan, Norway and Wales. The study concluded the main issue is the *implementation* of curriculum reform due its high cost, the uncertainty of outcomes and risk aversion of stakeholders, as well as tendency to prefer 'the status quo over changes' (OECD Education Working Papers, 2020, p. 9). This is evident with the response to Rose's parallel text, and the rejection of Allen's proposed textbook alterations. The review states that a new curriculum requires a clear vision of the purpose of the change, financial and human resources, long-term commitment *and* teacher professional development (OECD Education Working Papers, 2020). This is supported by recent research from Aivelo and Uitto (2019, 2021) who found that as well as the textbooks, teachers present either 'structural', 'hereditary' or 'developmental' emphases when teaching genetics, which correlates with resulting attitudes amongst students. Importantly, the study demonstrated that teachers with a 'hereditary' emphasis, which used humans as a context for Mendelian disorders without discussing complex human traits, had the strongest belief in genetic determinism. Those that emphasised the development of traits, complexity and epigenetics were found to have the weakest belief in genetic determinism, and also reported the highest affinity for genetics. Aivelo and Uitto claim to present empirical evidence that teaching Mendelian and classical genetics with an emphasis on hereditary aspects can lead to conceptions of determinism, and state the approach of the teacher is a major contributing factor.

If teachers and educators do not appreciate the need for an honest, modernised genetics curriculum, and the workload appears too demanding, reform efforts will have limited success. Teachers must be open-minded to modifications, whether that is interweaving new uses of language, theories and contexts into the current teaching, or reorganising the curriculum. This is also supported by Abd-El-Khalick, Waters and Le's study, reporting no change in the representations of the nature of science over the last four decades, despite international science education reform documents increasingly emphasising it in science education (American Association for the Advancement of Science, 1990; National Research Council, 1996). They suggest it demonstrates a 'complete disconnect between the authors and industry involved' in textbook publication, and forms naïve views amongst students over the nature of science (2008, p. 852). Other attempts to rectify textbooks and the curriculum during secondary school to incorporate the nature of science have also been unsuccessful (Holton, 1981; Klopfer & Cooley, 1963). Fullan (2015) argued that

[19] For further studies on curriculum reform in the 1980s in England and Wales see Goodson, 1989.

change cannot take place if individuals do not have the adequate skills to implement it. This aligned with Kisa and Correnti (2015) who suggest it is teachers' lack of knowledge or existing beliefs which prevent changes to the curriculum. Therefore, incorporating an awareness of the nature and history of science into the professional development of teachers appears crucial.

5.3 The Role of Interdisciplinary Perspectives

Other factors impacting genetics curricula beyond the textbooks and attitudes of teachers has been found to include the structure of universities and the struggle to recruit foreign scholars, as well as the 'intellectual conservatism' of central authorities (Burian et al., 1988, p. 369). The separation of disciplines and paradigms within the university system and across countries led to presenting genetics, embryology and development as separate entities. However, they are highly interlinked and knowledge of one provides insight into another. Furthermore, the instruction and passion within the teaching of one generation determines the practices which the next will pursue, so ideologies are maintained within certain scientific communities. For example, in France where genetics was not a part of textbooks before 1940s, students are thought to have treated Mendelism as 'a foreign paradigm of marginal importance, not worth close attention in the curriculum' (Burian et al., 1988, p. 369).

It is widely recognised that textbooks are the predominant resource for teachers planning to teach according to curricular standards; thus, they quickly become the curriculum (Chiappetta and Koballa, 2002). Therefore, if textbooks are not accurately presenting the developments, meanings and applications of scientific knowledge, teachers and students will be misled. dos Santos, Joaquim and El-Hani claimed this to be a problem of *all* school science knowledge, and recognise the burden that comes with maintaining an up-to-date curriculum. Rather than rewriting the whole curriculum, they advocate approaching genetics from a broader perspective and suggest a historically and philosophically informed approach would lead to a more 'thoughtful treatment of concepts and models' (2012, p. 573). Research has demonstrated there is a poor understanding of the influence of environmental factors on traits amongst trainee teachers, which favours a deterministic view and negatively impacts the outlook of the students (Aivelo & Uitto, 2019; Forissier & Clément, 2003). Furthermore, Gericke et al. (2017) unexpectantly found no significant correlation between increased knowledge about modern genomics and reduction in genetic determinism. Instead, overcoming genetic determinism may be better achieved by developing philosophical thought, for students and teachers to understand the impact of deterministic thinking, and approach genetics with a better awareness of its relationship with society. Promoting critical thought beyond simply presenting knowledge as 'facts' allows students with the tools to make their own decisions and is a valuable outcome of education.

Another interdisciplinary perspective arises from the BIOHEAD-Citizen Project's analysis of genetic determinism in teachers across nineteen nationalities (Castéra & Clément, 2008). They found variation according to country, and Castéra et al. (2013) suggested the reason that French teachers displayed less determinism than Estonian teachers was because philosophy was obligatory in French secondary schools, and only optional in Estonia. The philosophy curriculum requires students to discuss the inseparable relationship of nature and nurture in humans, therefore increasing students' awareness of genetic determinism. They propose using an epistemological and historical approach to genetics education, in

order to help teachers and students become more mindful of their own conceptions and reduce the tendency to think deterministically.

The Weldonian 'Honoring the Complexity' group describes a 3-year collaboration between the historian of biology Gregory Radick, the education psychologist Brian Donovan, the biologist-educationalist Michelle Smith and genetics teachers across the USA, to establish ways in which the curriculum *can* incorporate the wider environment and context of genetics. By engaging the teachers and different disciplines as well as the textbooks, this project brings hope for the future of a less deterministic approach and move from 'gene-as-character-makers' to a more contextual 'gene-as-difference-makers' (Radick, 2020, pp. 307–310). Rose's and Allen's cases demonstrate the need to include the history of genetic developments, for students to better understand the nature of scientific inquiry. However, this research group recognises that changes are needed by the teachers, as much as to the current curriculum. Without addressing teachers' approaches to genetics education, changes to the curriculum appear to have limited success at overcoming genetic determinism. Had publishers, course coordinators and students been more aware of the reasons for Rose's and Allen's changes, and the desire to teach about the development and progression of historical scientific models, the new courses may have been better received. It would improve science education by stressing the context in which theories are built and advance a students' understanding and most likely, their interest in the subject.

6 Conclusion

As textbooks form scientific disciplines through authors' selection and organisation of theory, they influence the resulting attitudes of students. In genetics, this is the 'gene for' conception of inheritance, emerging from Mendel's fixed one gene, one trait ratios. The results from Mendel's experiments on seven invariable, homozygous traits in highly selected peas have since been extrapolated into principles of human inheritance by developing a model of selective breeding at a time when eugenics was rising. The production of genetics as we know it is rooted in a larger dispute in which Bateson, Mendel's key proponent, successfully recruited scientists and published the first genetics textbook. In it, he presented Mendel's results in a way which supported his own ideology. Forming the foundation of genetics teaching ever since, students are led to follow Bateson's discontinuous approach to inheritance. Textbooks have oversimplified genetics by ignoring the context in which it developed, and using problem-solving exercises which encourage students to use and ingrain Mendel's principles. Now over a century later, popular genetics textbooks still often begin with the Mendelian concept of the gene (Flodin, 2009). Rose suggests many teaching courses which recognise difficulty in the history of genetics simply use a disclaimer at the beginning of the course, and 'leave the history of genetics to the historians'.[20]

Addressing the nature and history of science in education is important for developing scientific literacy. It has been argued that consideration of the credibility, conflicts of interest and potential bias better prepares students to deal with flaws in scientific claims, and to understand how scientists act to 'prevent, mitigate, or accommodate' potential sources of error (Allchin, 2011, p. 524). Specifically, studies found textbooks do not present the goals or limitations of models used to describe complex phenomena, leading to misinterpretations about the nature of genes and eventually political and socioeconomic consequences

[20] Pers. Comm., Steven Rose to myself (email), 28 Nov. 2020).

(dos Santos et al., 2012; Gericke & Hagberg, 2007). However, the difficulty in revising the curriculum has been demonstrated by claims such as Sang et al. (1976) of Rose's course as being 'too long, too advanced and too detailed', and the rejection of reorganising Allen's textbooks by his publisher. These cases present a tension between an honest representation of science and what many believe should be included. It varies across authors, time and place and leads to the incorporation of bias into scientific sources relied on as accurate, factual content. Changes to the curriculum may oppose existing ideologies and be rejected as a result. Therefore, the science curriculum becomes 'a social artefact, conceived of and made for deliberate human purposes' (Goodson, 1989, p. 131). However, reform efforts have endeavoured to remove Mendel from the focus and present a more continuous form of heredity originating with Weldon, Bateson's key opponent. Contextualising Mendelian genetics by including the history of experiments, responses and developments since encourages students to develop an understanding of science as a process of continual discovery, and to question apparent 'facts'. The aim is to reduce the application of Mendel's laws from a universal conception of heredity, and to limit the impact of genetic determinism. This is not as simple as it seems, and as demonstrated by the attempts made so far, there are many factors affecting the curriculum beyond the science itself.

Professor Steven Rose used an additional historical text to contextualise genetics and highlight Mendelian ratios as an interpretation of the data and a product of the time in history. This prompted controversy over the highly demanding content and timings of the course. Professor Garland Allen intended to modify his textbook to not start with Mendel and focus on molecular genetics, but was averted by his publisher believing it was too much for teachers to adapt. Both Rose and Allen were successful at presenting a form of genetics which placed less emphasis on Mendel and his fixed laws, with the aim to portray a less deterministic and more variable conception of heredity. They achieved this by discussing the historical and social factors which led to Mendel's success in highlighting reasons rather than just his results which led to him being perceived as the 'father of genetics', as well as altering the language to be less definite. However, their proposed changes achieved limited success due to time pressures in education, demanding workloads and poor acceptance by other members of the scientific and education community. My comparative study concludes that Allen's agreeable changes to using less definite language and supplementary textboxes created a less deterministic portrayal of genetics, without needing dramatic alterations. This demonstrates how the many factors controlling the production of the curriculum lead to science being outdated, biased and misleading. Ultimately then, with many conflicting interests surrounding education, major changes could be regarded too controversial, and smaller changes appear to be more effective. Time, resources and willing educators also limit efforts to reform the curriculum. Looking ahead, we must consider the balance between all of these.

There is a general lack of support for change exemplified by Rose's and Allen's cases, as well as the minimal research into genetics education and curriculum reform. Educators and scientists must be aware of the issue resulting from overemphasising Mendelian inheritance, while underemphasising the 'multifactorial nature of traits' (Tornabene et al., 2020, p. 1651). As demonstrated, it is difficult to significantly change genetics education without 'clear and evidence-based guidelines for teacher education' (Donovan & Nehm, 2020, p. 1456). Teachers need to be well-prepared to teach an unbiased, non-essentialist depiction of genetics. They must be able to address common misconceptions amongst students, to overcome misunderstandings which may later form deterministic attitudes. Therefore, further research is needed to understand the relationship between the teachers' own perspective and its impact on how they teach. It would also be interesting to see how an

increased focus on the nature and history of science could be incorporated into teacher training, and whether it would influence the learning outcomes of the students. It is clear that more research is needed to better understand the relationship between forms of genetic education and beliefs in genetic determinism (Gericke and Hagberg, 2007). Yet regardless, if those teaching genetics were more aware of the discipline's development in history, and the impact of using oversimplified models and language which enhances genetic determinism, then it seems likely that this would impact the resulting outlook of students. By being conscious of how deterministic views impact society, prejudices and health choices, teachers, educators and policy-makers would be more likely to view genetics as an area needing educational reform.

With the increased use of technology and advancements in science, we are opening up a world of genome sequencing, editing, screening and much more. Applied to medicine, this produces situations where individuals have to make life-changing decisions. It is crucial that these are not based on underlying misconceptions of genetics resulting from introductory genetics courses. Beginning genetics teaching with Mendel, as a hundred years' worth of textbooks has done, may lead to an overemphasis of his laws of inheritance and concerns of application to human heredity. We need to address the problem of changing genetics curricula in order to avoid misleading simplifications and educate students to think about complexity. To aid this, we must use the downfalls of previous attempts such as Rose, Allen, Radick and Lewis and Lysenkoism to deduce the best way to reselect and reorganise textbooks, and produce a science influenced by a wider contextual focus resulting from the present genomics age. Rose's example would suggest this is not including overly ambitious content, and Allen's case indicates that changes should not massively alter the organisation. Despite both intending to, neither were able to move away from the genetics course beginning with Mendel. Therefore, it is essential for teachers, educators and policy-makers alike to be open-minded to change and aware of the consequences of following a century-old form of science to explain human inheritance. Only by being better equipped to overcome this through training and new resources is it possible to modify the curriculum and remove Mendel from the focus of genetics education. I conclude by arguing that changing the emphasis of student genetics courses and teaching approach should create a more neutral understanding of human inheritance, in an attempt to tackle deep-rooted sexist, racist and determinist attitudes in society.

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