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Abstract

This paper reviews the rapidly developing field of epigenetics, providing an accessible explanation of the key ideas and some illustrative examples of work in the field. Although very much a biological discipline the implications of the developing knowledge in this area are very significant for educational psychologists and this paper aims to provide an introduction to what is becoming a very significant shift in how people think about learning and development. Understanding the processes that underlie epigenetic change and the research that the new knowledge is based on will be important for educational psychologists in order to understand this important developing area of thinking about development and learning. Consensus is growing that intergenerational transmission of epigenetic changes are a reliable phenomenon, establishing the principle of the inheritance of acquired characteristics. This contrasts starkly with models of biological determinism and provides a new way of thinking about educational and societal change.

Keywords: epigenetics; genetics; heritability; biological determinism; development.

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Epigenética: ¿Qué Necesitan Saber Los Psicólogos?

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Resumen

Este artículo revisa el cambiante campo de la epigenética, aportando una explicación asequible tanto a ideas clave como a ejemplos ilustrativos en esta área. Aunque se trata de una disciplina básicamente biológica, las implicaciones del creciente conocimiento de esta área resultan muy significativas para psicólogos educacionales y este artículo pretende proporcionar una introducción a lo que se está convirtiendo en un cambio significativo acerca de lo que la gente piensa sobre aprendizaje y desarrollo. Entender los procesos que sustentan los cambios epigenéticos y la investigación sobre la que se basan, será de gran importancia para los psicólogos educacionales a la hora de entender esta importante área de pensamiento basada en desarrollo y aprendizaje que está en constante progreso. Hay un creciente consenso que la transmisión intergeneracional de los cambios epigenéticos es un fenómeno fiable, que establece el principio de la heredabilidad de características adquiridas. Esto contrasta claramente con los modelos de determinismo biológico y aporta una nueva vía de pensamiento acerca de los cambios educacionales y sociales.

Palabras clave: epigenética; genética; heredabilidad; determinismo biológico; desarrollo

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In education, the perceptions people have about the impact of nature and nurture on learning and development hold great significance. Our understanding of genetic inheritance and its influence on a child can shape how a psychologist or teacher thinks about their work, it can shape school or college policy and it can shape legislation. A common sense understanding of genetic inheritance currently sits largely with the "Darwinian" tradition, although Darwin himself did not identify genetic mechanisms of course. In this way of thinking a genome is passed from one generation to the next. It is subject to random mutations, which may or may not give the individual an advantage. Selection of the genotypes (and phenotypes) that survive and successfully reproduce is guided by this process of random mutations of the genome and any additional advantage that a mutation in the genetic sequence bestows on the host organism.

Under the paradigm of Darwinian evolution education has a fairly limited role when thinking about change across generations. Educating someone has value for that individual during their lifetime and possibly for the society or community that they are part of as a result of what they can contribute. However, any changes a person makes to themselves (or is subjected to) during their lifetime do not get passed on to subsequent generations. A person who struggled with some aspect of life as a result of their genes might expect their children to experience the same struggle, no matter what that person has done in their life to remove barriers or overcome challenges for themselves. Their children would have to overcome them in the same way, from the same starting point. Our thoughts and actions might form part of the culture or knowledge base of the community the next generation are born into, but that new generation start with the same biological blueprint and have to learn (or re-learn) any behavioral adaptations or other advantages that previous generations acquired. The notion that life outcomes can be attributed to fixed biological factors is strong. In the long-term human beings are tied to processes that have a distinct 'biological determinism' (Lewontin, 1976).

Epigenetics is starting to offer a radically different perspective: that changes we make in our lifetime not only affect us but that these changes can be passed onto subsequent generations through genetic processes as well

as through culture and learning. This paper will explore this new thinking, explaining the scientific basis for the ideas.

It will start by describing the 'problem of missing heritability' that has been discussed in genetic research, and why is it not possible to explain human diversity through traditional genetics alone. It will then explain the fundamentals of epigenetics and how they potentially help solve this problem before exploring some specific examples of research that have developed our understanding of epigenetics over the last decades.

Finally, the paper will explore some possible implications of these ideas for educators and psychologists in particular. It will offer a new template for thinking about inheritance.

The problem of missing heritability

The human genome project came with great hopes for genetic solutions to many of the problems that human beings face. Heralded as a 'holy grail' of scientific achievement (Lock & Palsson, 2016, p. 76) it promised an explanation at an individual level for the diversity in human physiology, behaviour and psychology. Differences in our DNA would be identified and pinpointed so any unusual patterns in the DNA, perhaps caused by a mutation, could be mapped and used to help explain differences between us. Twin study research in particular has indicated that there could be a significant genetic component to psychological phenomenon as broad as happiness for example (Blum et al., 2009).

Twin study research has led to the hypothesis that much variation in human experience can be attributed to our genes. Comparing the life outcomes of genetically identical individuals in similar and dissimilar environments provided seemingly irrefutable evidence that 60% or more of variability between human beings could be attributed to genetic similarity or difference (Boomsma, Busjahn, & Peltonen, 2002).

Genomewide Association Studies (GWAS) take a very different approach to looking at genetic inheritance (Craddock, 2013). GWAS studies map millions of DNA patterns across many thousands of participants. One study for example (Chang et al., 2016) looked at the genetic code of over 2000 participants who had diabetes related cataracts and compared them to nearly 3000 controls. The participants came from a Scottish national dataset

on diabetes patients. The results found a specific gene that could be identified as having an effect in the development of cataracts in diabetes.

Twin studies have suggested that variation between human phenotypes is, for many characteristics, largely related to genetic influences. The huge power associated with a GWAS study held great promise for being able to pinpoint the specific genes that would explain specific differences that might be seen between humans. However, there was a problem. GWAS studies have identified over 1200 specific DNA patterns or pairs in the DNA sequence that are associated with 165 human diseases or traits (Zuk et al., 2012) but when the results are extrapolated they only account for 20%-30% of the variability between human beings. So on the one hand twin studies would claim that the majority (60% or more) of human variation is attributable to genetic variation, and on the other hand GWAS studies show that when you pinpoint specific DNA variations in population level data you can only explain 20%-30% of the variation. There was no easy way to explain the difference between the two and the gap has been termed 'the missing heredity problem' (Plonka, 2016; Zuk et al., 2012; Slatkin, 2009). In fact, this crisis in genetic research and the failure to identify how many human traits are directly linked to genetic variation is just the tip of the iceberg. Genetic expression is generally subtle, not specific, and the way that the environment can influence which genes are important and which are not is complex, meaning that there are many anomalies in genetic research. Anomalies where what is predicted by genetic mechanisms is not seen in reality.

Epigenetics has been highlighted as the most likely source for an explanation for what might be going on (Slatkin, 2009; Carey, 2011; Spector, 2012; Lock & Palsson, 2016). So, what is epigenetics?

Epigenetics: An introduction

To explain the significance of the shift in thinking that these ideas bring it is worth taking some time to describe the mechanisms involved.

"When scientists talk about epigenetics they are referring to all the cases where the genetic code alone isn't enough to describe what's happening – there must be something else going on as well" (Carey, 2011, p. 6).

There are many descriptions in the literature of the key epigenetic mechanisms that are involved. Genes are used as the blueprint for cells in the body, which in turn form a blueprint for organs and the body itself. The way that the human body (phenotype) develops is determined in no small part by the genetic code. However, the DNA sequence has to be 'read'. The process of reading a DNA code is controlled by Methyl groups and histones. Histones are coils of proteins that the DNA sequence is wrapped around when stored in a cell. The way in which the histones are attached to the DNA affect whether the gene is switched 'on or off'. This determines whether that piece of DNA has an effect or not on the developing person, and if it does have an effect, how it has that effect. So, in this way the same set of DNA in two different people can produce very different phenotypes.

DNA methylation (DNAm) is the process that wraps the DNA sequence with this additional layer of material that determines how the DNA is read. The DNAm process involves methyl groups being attached to the DNA. Methyl groups are molecules that become markers for other silencing proteins to interact with the DNA, methyl groups are not proteins themselves. These then form groups of proteins, including histones, that moderate, repress or silence the DNA sequences in the genes. Neither the presence of methyl groups or histones change the actual sequence of the DNA itself. They change the way it is used in a cell and how it is read by the body.

Williams and Drake (2015) give a summary of how life experiences, and particularly early life experiences, can 'programme' the genetic code through DNAm. Different patterns of methyl groups can change the organic structure of the body, create long term hormone changes, affect the hypothalamic-pituitary-adrenal axis (associated with many developmental conditions) and influence many other key developmental processes.

Taking a different perspective on the same problem authors writing from an evolutionary perspective exploring the archaeological information about genetics (Brooke & Larsen, 2014) have noted that there is an "established consensus that the essential modelling of the genetic code ended sometime in the Paleolithic". They argue that there can be no meaningful genetic explanations for human behaviors as genetic changes are so slow in terms of their effect on a species. They look to epigenetic changes to explain the way in which humans have responded so quickly and successfully to their environment over the last 10,000 years.

Epigenetics therefore provides the solution to the problem of missing heritability. The additional information present alongside the DNA itself helps explain why GWAS studies have not found that specific genes themselves predict very much of the variance in human life. It is the additional information that goes along with the genes that makes the difference. A fundamental point about DNAm is that how this additional information is wrapped around the DNA is often under our influence or our control. Something that the environment we are in, our life choices and experiences can alter.

It should be noted that recent reviews have highlighted the possibility of other processes and mechanisms that might be involved, and that although well described, the methylation mechanism might be one of several possible epigenetic processes (Scorza et. al., 2018).

Intergenerational transmission

A key aspect of epigenetic processes is that evidence is strongly suggesting that the additional information that surrounds the DNA sequence can be inherited by subsequent generations along with the DNA sequence itself. This finding has been trumpeted by proponents of epigenetics, highlighting the paradigm shift it represents. Ammaniti and Gallese (2014) for example describe the discovery of intergenerational transmission of trauma and resilience as revolutionary in the impact it has on how we understand inheritance, human development and emotional wellbeing. A ground-breaking paradigm shift and 'revolution' is also the kind of language used by Carey (2011), Plonka (2016) and Lock and Palsson (2016). These writers argue that epigenetic findings are forcing us to fundamentally re-appraise our thinking about genetic inheritance and the impact of environment on our life outcomes. Despite the rhetoric the shift in thinking has been gradual. Writing only a couple of years before Carey, Slatkin (2009) noted that there was still much to learn about the extent to which epigenetic changes could be inherited, and once inherited whether an epigenetic change would last and persist. Even some recent definitions of epigenetics still include note of caution:

> Epigenetic regulation—biological mechanisms that influence the expression of genes and which may be influenced by the cellular environment, over different time scales from seconds to minutes to hours, days, and years and perhaps (more controversially) across generations, and with different degrees of reversibility. Biological mechanisms (e.g., DNA methylation) that affect gene expression without changing DNA sequence. These processes may be involved in long-term developmental changes in gene expression (Thomas et al., 2015, p. 17).

It is important for those of us who are not experts in the field of biology or genetics (which the author is certainly not) to bear in mind the perspective of those who approach the topic with more caution. In addition to the cautious tone taken by Thomas above Cecil, Smith, Walton, Mill, McCroy, and Viding (2016) reviewed the evidence for epigenetic signatures for abuse and neglect, arguing that further replication will be needed before firm conclusions could be drawn. More recently still Scorza et al. (2018) have noted that despite a good level of evidence for intergenerational transmission in animal research there is still a need for more research in humans before we can say for certain that there is good evidence for these pathways impacting on areas such as disadvantage in human populations.

Nevertheless, other writers indicate a growing consensus in the research community that the changes that are made to methyl groups and histones can be passed from one generation to another and that they can contribute to developmental processes (Rutter & Pickles, 2016).

In 'Darwinian' evolution the organism gains an advantage because there is a random mutation in the genetic code itself. Subsequent generations will also inherit that altered gene. If the mutation is adaptive and gives them an advantage they will prosper. In the new paradigm life experiences programme how the genetic information is used by the body and are set as changes to DNAm. Through this mechanism the effects of these life experiences can also be inherited along with the DNA itself. "You can inherit something beyond the DNA sequence. That's where the real excitement of genetics is now" (Goldberg, Allis, & Bernstein, 2007, quoting Watson, 2003).

One of the most convincing examples of intergenerational effects is that of the Dutch Winter Hunger, or Dutch Famine.

The Dutch Famine

Many authors writing about the development of epigenetics highlight the significance of research into the Dutch famine or Dutch Winter Hunger (Carey, 2011; Spector, 2012; Rutter & Pickles, 2016; Scorza et. al., 2018). The situation in Holland in the winter of 1944-45 provided some unique conditions that have allowed researchers to investigate epigenetic processes (Heijmans et al., 2008). German restrictions on food for the Dutch population created a famine, while at the same time normal health records, food rations and health care were all maintained. Researchers were subsequently able to pinpoint individuals 6 or 7 decades later who had been conceived during this time, with detailed knowledge of the mother's health, diet and birth details. The research identified lower methylation in specific parts of the DNA sequence in these individuals. This was some of the first clear evidence that the impact of the harsh environmental conditions could be seen in the microgenetic makeup of an individual and is highlighted as some of the most significant research in the area (Rutter & Pickles, 2016). The impact adversity has on development has been explored in relation to other major events in history as well. The intergenerational impact of the Holocaust being a key example.

The Holocaust and intergenerational trauma

A large body of work has developed following extensive investigations into the experiences of Holocaust survivors and their offspring (Shmotkin et al., 2011; Kellermann, 2013; Yehuda et al., 2008; Yehuda et al., 2014; Yehuda et al., 2016).

A study of 211 adult offspring of Holocaust survivors (Yehuda et al., 2008) identified that a higher prevalence of PTSD, mood and anxiety disorders and substance abuse disorders were found in the offspring of survivors than demographically comparable Jewish controls. The investigation also identified that maternal PTSD made a greater contribution to transgenerational transmission than paternal PTSD. By 2014 Yehuda and colleagues (2014) had identified the first evidence of alteration to specific genes in the form of methylation associated with this inheritance. Later

research (Yahuda et al., 2016) has shown that the epigenetic effects are present in offspring who were conceived after the trauma took place.

Shmotkin et al. (2011) emphasize that it is that is not the trauma event that is transmitted, but the impact the event has on the person experiencing it. A wide range of factors moderate the degree to which the effects of a trauma are transmitted and can protect individuals. These include the quality of the marital relationships, the existence of wider support systems for the individual after the trauma and the use of defense mechanisms to 'isolate the effects of the Holocaust from crucial aspects of their functioning" (Shmotkin, 2011, p. 10). In this way it is argued that resiliency could be transmitted through the same epigenetic processes. And although trauma-based transmission can take place from children of Holocaust survivors to the grandchildren of survivors so can resilience to trauma.

Ammaniti and Gallese (2014) describe the epigenetic transmission of resilience and intergenerational responses to stress. Drawing on a wide range of literature including animal studies they note that research is concluding that "there is no significant main effect of genes, a marginally significant effect of environment, but a relevant significant effect of the G x E interaction" (p. 170).

Addiction

Often seen as an attempt to cope with adversity substance abuse and addiction is one of the areas that has drawn some interest. Cecil, Walton and Viding (2016) review what is known about epigenetic mechanisms in relation to addiction. They acknowledge that within the current literature on addiction most of the research has been based on animal studies rather than human participants. Nevertheless, they are able to conclude that there is 'tentative evidence for intergenerational transmission of DNAm patterns implicated in addiction'. They note a number of cautions however, including that it is difficult to conclude with certainty yet that DNAm is causally linked to addiction without longitudinal studies. These have not been set up in this particular area as yet.

So, there is now evidence from a range of different sources that epigenetic processes seem to play a significant role in responses to adversity. Key psychological responses such as resilience and addiction are being

linked to DNAm processes and there is growing evidence that this is inherited from one generation to the next.

The educational context: child development, learning and emotional wellbeing

As knowledge of epigenetics grows what other areas are being explored that are relevant to children's development, learning and emotional wellbeing?

Authors in pediatric journals have started to highlight the importance of epigenetic processes in young children's development. Williams and Drake (2015) write that

> There has been much interest in recent years in the role of epigenetic modifications in early life programming. Epigenetic modifications lead to changes in gene expression that are not explained by changes in DNA sequence, and during normal development, key developmental stages are characterized by epigenetic modifications that have the potential to be altered/disrupted by environmental cues (p. 1060).

The perspective taken is that those concerned with child development should know and understand epigenetic processes, because the science is robust enough for professionals to have confidence that developmental pathways are influenced significantly by epigenetic processes.

In terms of learning and learning difficulties Smith (2011, p. 356) reviewed the research looking at language and learning disorders and noted that there are perhaps a surprisingly a small number of genes that seem to be involved in early development of these skills, particularly the process of how growing neurons migrate within the cortex to their specialist areas. Smith notes that rather than specific genes for specific learning difficulties

> most of these candidate genes have been associated with several learning and language phenotypes, suggesting that they facilitate learning processes which are basic to learning reading and language……effects are seen for several genes that primarily affect autism or language but have also shown effects on reading.

So, genes don't affect single areas of learning difficulty in a specific way. The effects of gene expression happen across broad areas of learning and development.

As well as this non-specific gene effect Smith goes on to comment that although a few genes have been found that might play a role in overlapping areas of developmental difficulty

> ..very few coding mutations have been reported to account for their influence on these disorders. This has led to the hypothesis that mutations affecting reading and related disorders are likely to be in regulatory regions….[and that]… epigenetic controls of gene expression have been found that affect developmental learning disorders (2011, p. 356).

In short there are very few areas of the gene sequence itself that have been associated with learning or developmental difficulties, and where they have been found they are non-specific in their action. What is proving to be much more likely is that the epigenetic processes that regulate how groups of genes are used in growth and development are what make the differences between human beings. Language and learning difficulties are unlikely to have a specific genetic cause, but much more likely to result from epigenetic processes.

Finally, an example related to emotional wellbeing. Goodyer (2015) identifies that twin studies would typically estimate that overall genetic heritability of 'depressive symptoms' would be about 35%. This suggests that children's wellbeing is to a large degree determined by their genes. However, as with many other areas, molecular genetics (GWAS studies) has not replicated this figure. Of the GWAS studies in this area Goodyer writes that "Overall the findings do not support a strong role for genetic factors…implicating the importance of parent-child relationships" (p. 1065). Again, the problem of missing heritability indicates that if specific genes cannot be found through GWAS studies for 'depressive symptoms' then twin studies have effectively overestimated the variation that can be attributed to genes. Epigenetic processes provide the solution to this gap.

Across a spectrum of child development, learning and emotional wellbeing epigenetics is being highlighted as a crucial process to consider. What are the wider implications for the paradigm shift? How could it affect our understanding of how we effect change in our lives?

The inheritance of acquired characteristics: A new model of biological inheritance?

Through epigenetics a new model is emerging, and it offers a radically different understanding to our existing notions of Darwinain or neo-Darwinian evolution. The new conceptualization is that acquired characteristics can be inherited. This is not a completely new perspective. Scorza et al. (2018) note that the work in this area is akin to 'Reviving Lamarck'. Lamarck, a contemporary of Darwin, developed a theory of biological inheritance that was very different to Darwin's, whereby efforts of a creature to change its life could be inherited. According to Spector (2012) the most quoted example of Lamarckian evolution is that given by Lamarck about giraffes. The giraffe strives to reach food on higher and higher branches. The giraffe could, through effort, elongate its neck and then would pass on a longer neck to subsequent generations. Jablovka and Lamb (1995) discussed early epigenetic thinking in relation to Lamarckian evolution, highlighting the significance of the inheritance of acquired characteristics. Although discounted by the scientific community at the time strands of Lamarck's thinking not hold true and have the potential to radically alter the way we might think about how we effect change in our life and what the implications of this are. In a Lamarckian or neo-Lamarkian world the changes you make in your lifetime can improve your life and are passed to your children, and their children, through epigenetic processes. Could being in an environment where developing good language skills and learning to read make it easier for your children and your grandchildren to learn to read in some way even before the impact of their own childhood and education is considered? Currently an answer to this question would be little more than speculation, but findings are suggesting that such mechanisms might exist.

Implications for psychologists in education

Although more research in humans is clearly needed, (Scorza et al., 2018), the implications of the emerging understanding of epigenetic processes on learning, education and development could be profound. If the things we do in our life can affect our own epigenetic map and then that map can be transferred to our children and their children, there could be some very

different ways of thinking about some aspects of educational psychology. Epigenetics could help us understand some long-standing conundrums. For example, a number of authors (Thomas et al., 2015; Brooke & Larsen, 2014, and Plonka, 2016) highlight that although twin studies seem to suggest that IQ is highly heritable the rise in IQ scores across generations (the 'Flynn effect') cannot be explained by changes in the genetic code as the pace of change is simply too fast. Epigenetic processes are being suggested as the solution to solving this problem (Greiffenstein, 2011), and although the evidence may only be emerging it has the potential to re-shape our thinking about this question fundamentally.

The approach someone takes to parenting might affect their child's resilience to stress and in turn change the epigenetic map for their generation and the subsequent generation. It is also conceivable that efforts by society, schools and teachers to increase language acquisition and literacy skills would also create an adaptive pattern whereby subsequent generations benefit from the efforts that were made at the level of biological inheritance.

Perhaps the most significant potential implication lies in the way we think about equality in society and the challenge that epigenetics brings to notions of biological determinism. To what extent are differences between us a result of things that we can change and effect and to what extent they are fixed? Epigenetics has the potential to fundamentally change how educators and society think about variation across the population. As Lewontin wrote in 1976

> The idea that inequalities are a structural element of our social organization is not a popular one and not surprisingly is regarded with hostility by the governmental, educational and information-producing agencies of our society. The alternative, which has proved more palatable and, of course, more serviceable, is that our society is pretty much as fair as any society can be and that the inequalities we observe are the irreducible differences resulting from basic biological difference between people. This is, in effect, the ideology of biological determinism (p. 6).

However, if we can change the biological inheritance we pass on by living differently, if genetics alone provides only a small explanation of the variation we see between individuals and what might explain more are the environmentally influenced mechanisms, such as DNAm, then many assumptions underpinning our collective thinking about development, education and psychology will need to change.

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