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Epigenetic metaphors: an interdisciplinary translation of encoding and decoding

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Looking at the new and often disputed science of epigenetics, we examined the challenges faced by scientists when they communicate scientific research to the public. We focused on the use of metaphors to illustrate notions of epigenetics and genetics. We studied the "encoding" by epigeneticists and "decoding" in focus groups with diverse backgrounds. We observed considerable overlap in the dominant metaphors favored by both researchers and the lay public. However, the groups differed markedly in their interpretations of which metaphors aided understanding or not. We conclude by discussing the role of metaphors and their interpretations in the context of a shift from pre-deterministic genomic metaphors to more active, dynamic and nuanced epigenetic metaphors. These reflections on the choice of metaphors and differences in encoding/decoding are important for science communication and scientific boundary-maintenance.

Keywords: epigenetics; gene–environment interaction; metaphors; media

Introduction

The field of epigenetics is still relatively unsettled and contested, full of controversies, hype and skepticism, both within and beyond the scientific community (Morange 2006; Pickersgill *et al*. 2013). There is a significant gap between public opinion (usually fueled by media sensationalism) and critical expert views of academic researchers. By looking at a new science in its emergent and disputed stage, exposing the usually latent scientific boundary-making (Gieryn 1983; Tolwinski 2013), we examine the challenges faced by scientists when communicating about a new and controversial field to lay audiences, specifically in a non-Anglophone country.

A recent popular science film entitled "The New Secrets of Our Inheritance" released by ARTE in 2015, which we use for this study, begins by introducing the field of epigenetics as follows:

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> Our hands, our eyes, our face, our all body is an aggregate of billions of cells. At the heart of each of them is nestled the DNA, the one that we received from our parents and that we'll transfer to our children. What is exactly passed from one generation to the next, from one cell to the next? We know that DNA is transmitted, but not only DNA. Identical twins have the same DNA, the same genome, yet they are physically different. How is this possible? … if we view the genome as a book then it can be read in many different ways. Scientist have long thought that DNA alone ruled our biologic destiny. Today they're discovering another world: We're becoming more and more aware that DNA doesn't explain everything … All over the world, biologists are exploring this new mystery. (http://www.arte.tv/guide/fr/052761-000-A/les-nouveaux-secrets-de-notre-heredite)

This introduction illustrates the challenges of communicating a new science and the common strategy to reframe old scientific metaphors (genomic DNA as "a book") to address new scientific paradigms (the editions of a book can be very different from each other and each book can be read in different ways). The sociological critique of the hype surrounding the mapping of the human genome – "led astray by genetic maps" (Lippman 1992) – now arguably finds support in the new biological paradigm of epigenetics. However, relatively few studies have looked at how the new science of epigenetics is metaphorically encoded (by scientists) and decoded (by lay people).

Epigenetics, broadly defined, denotes heritable changes in gene expression that do not involve changes in the DNA sequence. Epigenetic events can be influenced by several factors including age, the environment/lifestyle, and disease, and can also provoke disease pathologies. Epigenetic modifications play critical roles in normal cell differentiation, as well as in diseases such as cancer. Epigenetic changes are initiated and sustained by at least three types of molecular mechanisms, including DNA methylation, histone modifications and regulatory non-coding RNA (Egger *et al*. 2004; Feil and Fraga 2012). Epigenetics has been referred to as one of the "next revolutions" in science (Meloni and Testa 2014). The general aim of this study is to examine the challenges faced by scientists when they communicate epigenetics research to the public and their choice of metaphors (encoding) and how lay audiences receive and interpret these metaphor messages (decoding).

A major part of epigenetic research deals with cell differentiation and developmental pathways, in either normal physiological or disease contexts, such as cancer (Feinberg, Koldobskiy, and Göndör 2016). Some epigenetics studies investigate animal models, such as the phenotype of the queen bee which is not genetically determined, the yellow (agouti) mice in which coat color variation is correlated with nutritional and environmental influences on the fetal epigenome (Dolinoy 2008), and inheritable stress syndromes in rodents (Szyf 2014). Epigenetic research of special relevance to the social sciences falls under two inter-related categories, both of which are somewhat controversial: (i) "epidemiological epigenetics" focuses on epigenetic markers in the general population which correlate with the effects of stress, diet, lifestyle etc., on physiological and behavioral changes. For example, a Scottish study (McGuinness *et al*. 2012) suggested that socio-economic status affects global DNA methylation of white blood cells in adults. Studies in the U.S. linked PTSD to methylation states affecting genes that contribute to immune system function (Uddin *et al*. 2010; Smith *et al*. 2011). Another U.S. study examined the developmental origins of social disparities in cardiovascular health (Kuzawa and Sweet 2008). (ii) "Transgenerational inheritance" focuses on particular social and historical contexts where early-life experiences affect adult life and offspring via epigenetic mechanisms of intergenerational transmission (Heard and Martienssen 2014). Examples include the study of long-term effects of the Nazi blockade of Holland in 1944 (Dutch Hunger Winter) which is today linked to second-generation effects (Painter *et al*. 2008). Another example is a study of higher rates of post-traumatic stress amongst Israeli soldiers who are the offspring of Holocaust survivors and potential epigenetic programming of their stress hormone system (Yehuda and Bierer 2009). There is relatively little research addressing the public perception of these scientific studies, which may be misconstrued by popular notions of race and class (Mansfield 2012).

Metaphor as a tool of theory building and popularization of science

Metaphors pervade all human discourse and scientific discourse as part of it, where they have an important function in the process of modeling reality, enabling comparison between two seemingly dissimilar concepts through carrying (*pherein*, in Greek) over (*meta*, in Greek) a word from its normal use to a new use (Goatly 2000; Maasen and Weingart 2000). If we live by metaphors (Lakoff and Johnson 1980) and human cognition requires comparisons embodied in physical and social experiences, then metaphors are not mere linguistic embellishments, but powerful tools for communicating knowledge and building theories. To make sense of and communicate knowledge about the macroscopic and the microscopic, about galaxies and molecules, scientists need metaphors grounded in our human, meso-cosmic experiences (Vollmer 1984). For example, Robert Hooke was the first to use the term "cell" when an image of a piece of cork under his microscope reminded him of the small rooms occupied by monks in monasteries, and Huygens used water waves to theorize that light is wavelike (Niebert and Gropengießer 2015). We still use these metaphors, which expand as well as constrain our worldview.

Thus, the analysis of metaphors in popular science is important for charting the historical and political developments of social representations in that field (Farr 1993; Gaskell 1999). Metaphors in science are so ubiquitous that we have to some extent become blind to their existence. Metaphorizing genes as "books", "blueprints" or "codes" has guided research in molecular biology for decades while being criticized as deterministic and overlooking complex gene-gene and gene-environment interactions. Metaphorizing genes as "recipes" might introduce the role of plasticity, time and the environment. Yet it has also been criticized as differing little from the blueprint/code metaphor, both essentially representing a static set of directions for producing a tangible material product (Taylor and Dewsbury 2018). While we may not be able to conceptualize, or communicate, abstract scientific phenomena without employing such metaphors, we must also recognize their limitations, as well as their potential to constrain interpretations of natural processes. Furthermore, metaphors activate diverse, context-dependent meanings as well as varying connotations amongst different audiences, thus highlighting the need for more empirically grounded research in critical discussions of metaphor use in the life sciences (Condit 1999a, 1999b).

Encoding epigenetics: from book and blueprint to cooking and music playing

Substantively and metaphorically, epigenetics inevitably builds on our knowledge of genetics. We can, therefore, expect that epigenetic metaphors will build on and extend the "grand" metaphors/narratives of popular genetics, such as the "book", "blueprint" and "map" of life, as well as the "code" and "software" of life (Nelkin and Lindee 1995). Intriguingly, while the grand metaphors of genetics expressed the hope that DNA holds the keys to the secrets of human life and health, the more reserved and necessarily additive metaphors of epigenetics are perhaps connected to the realization that DNA is "not the whole story" (Nerlich and Hellsten 2004; Stelmach and Nerlich 2015). For example, the focus has shifted from the "book" metaphor of DNA to more dynamic aspects of reading/writing, including punctuation and highlighting (Hellsten and Nerlich 2011; Calvanese, Lara, and Fraga 2012).

Epigenetics has also spawned a new set of metaphors linking genes and environment. One of these is (epi)genetic *memory*, storing traces of past experiences which may influence future generations. Music metaphors are also prominent in descriptions of epigenetics, where "the pianist corresponds to the epigenetic processes that 'play' the otherwise static linear information represented in DNA" (Klinghoffer 2012). Similarly, scientists have used technological metaphors of epigenetic tags as the "dimmer switch" or "the marker" (Stelmach and Nerlich 2015).

Amongst the different descriptions of epigenetics, some abandon code and information metaphors, choosing to highlight instead the physical, corporeal nature of genomic expression (especially in chromatin research; see Barnes and Dupré 2008; Deichmann 2015; Lappé and Landecker 2015). This perspective emphasizes a diversion from the "flat language" (Meloni 2018) of DNA information and the genome, adding a focus on how DNA sequences are spatially located within the complex 3-D scaffolding of chromatin and chromosomal domains. The linear sequence of DNA may not change during an organism's lifetime, but its organization and chromatin packaging can change. As Meloni (2018) notes, this shifts the perspective, making the possibility of *a* "plastic genome" both theoretically and experimentally salient. Indeed, this perspective endows the DNA with a lifespan or a biography – a cumulative spatio-temporal experience physically registered "in the three-dimensional shape of the chromatin fiber" (Lappé and Landecker 2015, 153).

As a potential bridge between the DNA and its surroundings, epigenetic marks can be considered as a connective platform. Although still in its infancy, the scientific and metaphorical significance of epigenetics for the social sciences lies in its potential to reconnect sociology and biology in new and exciting ways, both substantially and epistemologically. Although molecular epigenetic research is highly biochemical, it is of substantive interest to sociologists, because epidemiologic and environmental epigenetic research might be able to track mechanisms by which social forces – from pollution to nutrition to mothering to traumatic experience – become molecularly embodied, affecting gene expression and inducing durable changes in behavior and health (Jablonka and Raz 2009; Landecker and Panofsky 2013; Meloni 2014a). From the perspective of the sociology of science, contemporary epigenetics research can also be considered as a novel "post-genomic" phase that helps us to understand the historiography of genetics and the politicization of human heredity (Lock 2015; Meloni 2016). From the perspective of social theory, epigenetics has been described as a framework for rethinking the relationship between the biological and the social world and the *nature/culture* dichotomy (Goodman, Heath, and Lindee 2003; Rose 2013; Meloni 2014b).

A growing debate over the (mis)representation of genetic knowledge in the media and among the public has emphasized the need to counter genetic determinism and reductionism (Condit *et al*. 2004; Condit 2007, 1999a). Indeed, knowledge of epigenetics – propelled by a recent flock of popular books (Carey 2011; Francis 2011; Woodward and Gills 2012) – has an important role to play in this. In the recent British television series, "Brave New World", hosted by physicist Stephen Hawking, the veteran presenter of TV nature and science programs, David Attenborough, states: "I think the most significant discovery in the last decade or so has been the recognition that genetics is not just a matter of chromosomes". However, as popular science education focuses on Mendelian genetics, it might bias and confuse lay peoples' interpretations of epigenetic concepts.

As an empirical framework for studying how metaphors activate diverse, context-dependent meanings as well as varying connotations amongst different audiences, we employ Hall's (1973) model of encoding/decoding, which evokes the role of audiences, particularly the diverse and differentiated ways in which they interpret or decode meanings based on individual and group experiences (Hall et al. 1980/2006). Encoding/decoding thus serves as an epistemological framing for the diverse interpretation of communication: what the sender (producer of metaphor) intended to convey is not necessarily what the receiver (the audience) perceives of what was communicated (Shaw 2017). The challenges of communicating about a new and controversial field such as epigenetics to lay audiences can represent a "struggle for meaning" (Fiske 2011, 93). In their simplest categorization, decoding processes include differentiating between dominant-hegemonic, negotiated, and oppositional readings of texts. (i) A **dominant position** of decoding is where the TV/film consumer takes the actual meaning directly, decodes it exactly the way it was encoded, and reproduces the intended meaning. Within the context of our study, a dominant decoding would be one that reflects the scientific conceptualizations of epigenetics. (ii) A **negotiated position** is one where the decoder acknowledges the dominant message, but simultaneously resists and modifies it in a way which reflects her/his own experiences, interests and beliefs. Negotiated decoding evidently encompasses a wide spectrum, in need of more nuanced sub-categories that go beyond Hall's original articulation. For example, a negotiated position could reach a different conclusion (than the dominant one) or reach the same conclusion, but for substantially different reasons. (iii) Finally, in the **oppositional position** the decoder resists and rejects the dominant message and its premises, which in our case would be the scientific conceptualization of epigenetics with its underlying outlook and premises. In Hall's original articulation these decoding positions are shaped within Marxist relations of production. In our study, we focus on their semiotic aspects. Previous examples employing Hall's model for analyzing audience decoding of films communicating messages about genetics include Raz *et al*. (2016) and Raz (2003).

Methodology

To explore the challenges of communicating about epigenetics, we used a dual approach that involved interviewing both the "encoders" and the "decoders" separately about their understanding of the metaphors used in the ARTE film about epigenetics, which we used as a common basis for discussions. Our study draws on the following research design: (i) we conducted interviews with four epigenetics researchers (three of whom featured in the ARTE film) about which metaphors they found most "helpful" or most "misleading" in communication about epigenetic research. We asked them to discuss the main metaphors they thought were used in the ARTE film, as well as to suggest other metaphors. This part of the study established the expert "encoding" of metaphors regarding epigenetics. (ii) Six focus groups (FGs) consisting of 46 participants were conducted in 2017–2018 in Paris, France (Table 1). After watching the film, the participants filled a questionnaire assessing their knowledge of epigenetics based on the film and their reaction to the metaphors used in the film (see Appendix 1). This was followed by a discussion in which the participants explained why they see some metaphors are helpful or misleading, suggested new metaphors, and commented whether the discussion changed their views on these metaphors. This part of the study examined the "decoding" by lay people of metaphors related to epigenetics.

By controlling for the educational orientation (biosciences vs. humanities) of the participants and assessing their knowledge, we could investigate correlations between educational orientation, knowledge and decoding positions. The focus

Table 1. Focus groups included in the study.

Group #	Participants	Number and gender	Age range (years)	Educational background	Date
FG 1	genetics students	7 (M = 3, F = 4)	22–30	MSc genetics, biology, medicine	6/11/2017
FG 2	biology and medicine students	12 (M = 3, F = 9)	23–30	MSc biology, medicine	6/11/2017
FG 3	biology and medicine students	10 (M = 3, F = 7)	20–28	MSc biology, medicine	6/11/2017
FG 4	humanities students	5 (M = 4, F = 1)	27–36	MSc-PhD humanities	21/11/2017
FG 5	humanities students	4 (F = 4)	19–21	BA humanities	22/1/2018
FG 6	high school generalists students	8 (M = 1, F = 7)	17–18	High school	14/2/2018

group (FG) methodology offers a chance to assess what participants bring to the group and how group discussion potentially changes personal opinions, thus constituting "thinking societies in miniature" (Bloor *et al*. 2001). The areas of conflict and consensus that develop in FGs can therefore teach us about social processes that underpin public reception (Marková *et al*. 2007). Finally, comparing the views of epigenetics experts and lay people enabled us to contrast encoding and decoding in an unprecedented way. Further analysis of themes that emerged from the discussions illustrates how participants considered the metaphors to be meaningful.

We made no assumptions regarding the objective determination by participants of the usefulness, accurateness or any other feature of the metaphors discussed. We asked them to evaluate the metaphors in order to propel and guide the discussion and to encourage deliberations about the meanings they attributed to these metaphors. The issue of "accuracy" judgement was suggested by participants and not by the interviewers. The metaphors were used as common units of inter-subjective meaning to connect between encoding and decoding. We also encouraged participants to suggest and justify other metaphors, and these became part of the discussion and the analysis.

Each FG meeting began by showing the film about epigenetics made by ARTE, "Les nouveaux secrets de notre hérédité/The new secrets of our heredity" (2015; directed by Laurence Serfaty), available in French and English. In all FGs we used similar questions concerning relevant background variables such as age, education, gender, country of origin, and religiosity; knowledge of epigenetics; and preferences and views regarding epigenetics metaphors (see Appendix 1). The knowledge questions were developed based on topics shown in the ARTE film, and after being validated by an epigenetics, experts were used as a trigger for the discussion. We later analyzed the knowledge score for correlations with the decoding positions. Knowledge grades were computed by adding the number of correct replies to all the questions. The epigenetics metaphors were based on those highlighted in the film and by the epigeneticists we interviewed. They matched, in general, the list of epigenetics metaphors found in the popular scientific media (Stelmach and Nerlich 2015), including the metaphors of the "software/code", the biochemical "landscape/map", the "book", genetic "memory", the "pianist on the genome's keyboard", "punctuation", and the "architect's blueprint" (see also Ouzounis and Maziere 2006; FrameWorks Institute 2010). Participants were asked to grade each metaphor as helpful or misleading on a scale of 1–10. To select the most helpful/misleading metaphors, we counted the frequencies of metaphors with a grade above 9 in each category within each group. In the discussion that followed, participants were asked to reflect on how they perceive the most helpful/misleading metaphorical models, including suggesting new metaphors.

Group discussions were audio recorded and transcribed. Discussions were held in French or English; for the purposes of this paper, all quoted examples were translated into English. To ensure anonymity, all participants were given codes. The transcripts were analyzed thematically to uncover discursive themes and categories of themes recurring within and across groups (Denzin and Lincoln 1994). The quotations given illustrate the range of responses regarding the emerging themes. Due to the small number of respondents in this exploratory study, we used descriptive statistics for the knowledge grades and the metaphor preferences.

Findings

Epigenetics: encoding by scientists

Helpful metaphors: the musical score and the cookbook

The first part of our study used interviews with epigeneticists to investigate their use of metaphors. All the experts interviewed participate actively in research, as well as communicate epigenetics research to students and to the lay public. The interviews with epigenetics experts revealed that musical metaphors, such as "the pianist on the genome's keyboard" and "the symphony in your cells" were considered the most helpful for understanding and communicating epigenetics. One scientist explained that he uses "violinist" rather than pianist, because

> in orchestras the violinists have to decide how they will play their sequence: the musical phrase can start from one extremity of the bow, or it can start from the other end – pushing or pulling the bow. It impacts the color of the music. In the orchestra the violinists have to have the same movements. So, in the rehearsal the violinists agree where to start. There is a little conventional mark that the violinist will write on the score. It's called bow notation. (Interview A)

This image brings together two dynamic metaphors: music playing and notation. The positive value of the music metaphor, for all the interviewees, was that it brought together three components in a manner that people could relate to: (i) the written message (DNA represented by the musical score), (ii) the interpreter or decoder (epigenetics, represented by the musician), and (iii) the environment. Musicians can have the same sheet music, but when their interpretation or the environment changes then the music is different. As one of the interviewees stressed, the environment can have a tremendous impact; playing in Carnegie Hall is different from playing in a metro station. That was seen as a helpful aspect of the metaphor, because epigenetics is influenced also by the environment. Moreover, as bow notation is written with a pencil and can be erased and re-written, it could be compared to methylation – the epigenetic notation of genomic DNA. Epigenetics is the way the musician interprets the score, the music which is written in the genome. Musicians can emphasize different parts of the musical score, just like epigenetics does with genes in the genome.

Interviewees also acknowledged several limits of the music metaphor. First, playing music does not produce an object, contrary to the cook that produces a physical object (discussed below). Second, the problem of personification: who is the player/pianist/violinist/conductor? The scientists raised additional, more philosophical, levels of interpretation, with open questions whether "there a composer to the genomic score". Third, the issue of superficiality: environmental modulation of epigenetic states does not just turn the music (genes) on and off or make it louder – it is more complicated than that.

Another metaphor which the scientists agreed was helpful was cooking; if the genome is represented as the "cookbook of life", then epigenetics can be presented as the cook. Different cooks will prepare the recipe differently. Once again, the emphasis was on the three components: (i) the message (the DNA text of the cookbook or the recipes), (ii) the decoder (epigenetics represented by the cook), and (iii) the environment (the kitchen and the ingredients). As one scientist put it, "Nobody says that the recipe has produced a tart, so nobody should say DNA has produced a protein." Moreover, the two metaphors could be combined:

> You can underline the recipe, but also the history of the cook, the way s/he works, and epigenetics is not simply marking things. This is the easiest part, but the whole constitution of the cell and the hormones are part of the epigenetic system […] the decoding is not simply marking things in the text, but all the experience of the organism. You can have proteins which are bare or not and which change the way you read the DNA. A repressor would repress a gene; the classical example of a repressor that enhances production … If you stopped producing this protein, then you start activating the gene. (Interview B)

Misleading metaphors: maps, signatures, memory and blueprint

The interviews with epigenetics experts also highlighted metaphors that they considered misleading; namely the map, the blueprint and the code/software. This was often connected to the use of these metaphors to explain DNA and genetics, before epigenetics emerged as a discipline. They were, therefore, regarded as too restrictive and outdated, as the following quotes from different epigenetics researchers illustrate:

> The map has a very restrictive definition, only the nucleus, does not include hormones, the proteins. (Interview A)
>
> The signature effect … something is needed – it is like the environment itself puts the signature, what about the mechanism, where is the epigenetics? (Interview B)
>
> Genetic memory – that is confusing. The methylation does not belong to the gene. The gene does not remember the environment except for selection. It's something else. (Interview A)
>
> The blueprint is very problematic. Code is very bad; the epigenetic code is terrible. Why? It gives the idea that we would be predictive, decipher, based on the code. (Interview D)
>
> Biologists use the concept of translation not as a metaphor. When biologists talk about post-translation this is not metaphor. […] Architectural blueprints, that is a concept that scientists really stopped using, they also abandoned the word "program" – too orderly and linear. (Interview B)

The experts felt that scientific insights could still be communicated by explaining why the metaphor of memory was misleading, as the following quote by an epigenetics researcher illustrates:

> We use genomic imprinting, but in a very specific way, to denote a very precise mechanism during development. The genome can retain daily interaction, there is memory, epigenetic scars, traumatic events leaving traces … Cellular memory, which would be extra-nuclear, cytoplasmic epigenetics. That is unclear. Marks like methylation, that's the imprinting mechanism, as a biomarker of memory. It's nice because of the idea you have a past. Random and limited like personal memory. That's quite nice. I quite like it, but you have to spend time to explain it. The idea is a trap … crossing too many metaphors, Freud would say memories of childhood, is that inscribed genetically? That's seductive but also misleading. Memory is linked to the brain, that links epigenetics to neuro, that's misleading. Memory is also taken by immunologists – infection and epigenetic memory, very seductive but not yet convincing. Postnatal trauma – that's a memory issue, an example would be stress due to hunger … it's not clear how far we should take it. Useful and problematic at the same time. (Interview B)

Exploring new metaphors: landscape punctuation

The use of metaphors in epigenetics goes back to its very origins; the epigenetic "landscape" was originally a metaphor introduced by Conrad Waddington (1905–1975), a biologist who is given credit for coining the term "epigenetics". The (contemporary) epigenetics researchers we interviewed confronted the landscape metaphor with ambivalence. On the one hand they viewed it as something of the past, but on the other hand they considered it as an important signal in need of updating. In Waddington's classical conceptualization, the "landscape" denoted cellular differentiation induced by developmental mechanisms: even though cells share an identical genotype, embryonic development generates a diversity of cell types with disparate, yet stable, profiles of gene expression. Thus, cellular differentiation may be considered as an epigenetic phenomenon. At various points in this dynamic visual metaphor, the cell (represented by a ball) can take specific permitted trajectories, leading to different outcomes or "cell fates" that are largely governed by changes in what Waddington described as the "epigenetic landscape" (Waddington 1957; Figure 1).

We noted that the epigenetics experts acknowledged the importance of the landscape metaphor, while at the same time questioning how to develop it, as illustrated in the following quotes:

> It's Waddington's image, but it needs to be developed. (Interview A)
>
> Some metaphors are useful at the beginning and then get lost, like the epigenetic code and landscape. (Interview B)
>
> [the landscape] It's useful because it's visual, but even Waddington wasn't clear about it. He left it as a visual legacy. Everyone uses it in a completely different way. (Interview C)

Some of the epigenetics researchers that we interviewed expressed their opinion that the landscape metaphor could be the basis for new metaphorizing:

> [the landscape] that's quite a useful image, but I think about DNA as black and white and two dimensional. The epigenome gives it a third dimension. It's packaging the DNA into a 3-D shape, packaging and bundling the DNA. That provides a template where the interacting proteins can come and interact.
>
> [the epigenome] It's a sculpture, it sculpts DNA into a shape. A landscape is a shape, the genomic landscape in which this particular gene finds itself. Some of this

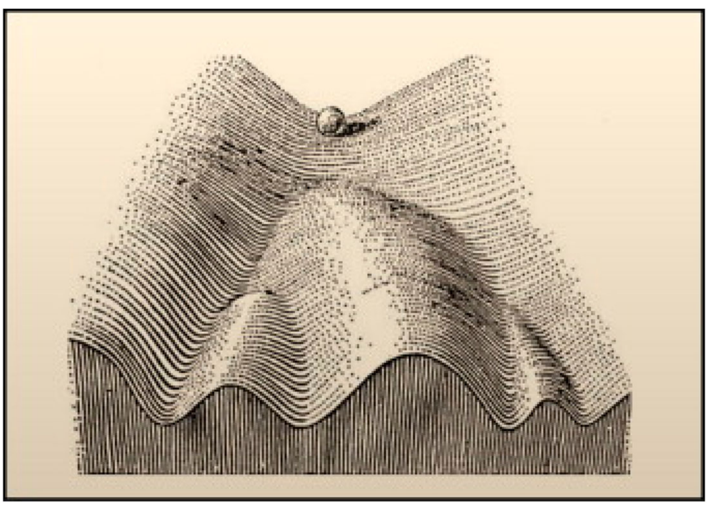

Figure 1. Waddington's classical epigenetic landscape.

> landscape can have more liquid or hydrophobic regions … Chemical properties of the molecular packaging, voltage, density, that can influence the function of the DNA. The epigenome is that landscape punctuation where the DNA is the scaffolding of the sculpture. (Interview C)

Notably, in one recent scientific review of epigenetics, the landscape metaphor was playfully transformed into a pinball machine (Goldberg, Allis, and Bernstein 2007).

Part two: decoding by lay people

The second part of our study focused on how the metaphors used by researchers in epigenetics are perceived by the general public. First, we present a quantitative overview of the attitudes of our respondents towards the metaphorical communication of epigenetics, to compare their subjective decoding with the encoding of epigenetics experts. We then address other questions raised in the focus group discussions about the metaphors of epigenetics and the meanings participants attributed to them. One set of focus groups included medical and scientific students, while the other consisted of students with non-scientific backgrounds. As expected, the knowledge grade of the genetics/medicine students (range: 7.14–8.5, $M = 7.88$) was higher than the humanities/generalist students (range: 5.4–8.4, $M = 7.35$). Table 2 summarizes the most helpful/misleading metaphors according to frequency, within and across FGs in the two categories. While participants had diverse choices and the distribution of frequencies was never equal across groups (as expected), selecting the 3 most helpful/misleading metaphors according to the combined frequencies across groups reflects representative patterns. It was intriguing to find certain metaphors coming up repeatedly as helpful/misleading in the different groups. We did not find correlations between knowledge and perception of metaphors.

Overall, in the FGs of the genetics/medicine students, the most helpful metaphors were the *pianist*, *memory* and *punctuation*, while the most misleading metaphors were *blueprint*, *software* and *map*. In the FGs of the humanities/generalist students, the most helpful metaphors were the pianist, software and landscape, while the most misleading metaphors were blueprint, map and (also) software. The pianist was seen as the most helpful metaphor across all groups, in line with the preferred music metaphor of the epigenetics researchers. In addition, software, blueprint and map were considered the most misleading metaphors across all groups, consistent with the same metaphors rejected by epigenetics experts. However, *memory* and *software* – two metaphors rejected by the epigenetics researchers – were selected as the most helpful by the genetics/medicine students and humanities/generalist students.

In general, almost all participants in the FGs had clearly defined views regarding the meaning of the metaphors, and most participants said they did not change their mind based on the discussions. The finding that preference for metaphors was highly individual and stable received further support from the observation that

Table 2. The three most helpful/misleading metaphors according to frequency, within and across FGs in the two categories.

	Genetics/medicine FGs			
	FG 1 (7)	FG 2 (12)	FG 3 (10)	Total across FGs
3 Most helpful metaphors (frequency)	Punctuation (4)	Landscape (4)	Pianist (7)	Pianist (9)
	Memory (4)	Memory (4)	Punctuation (3)	Memory (8)
	Pianist (2)	Book (3)	Recipe (3)	Punctuation (7)
3 Most misleading metaphors (frequency)	Software (4)	Blueprint (5)	Software (4)	Software (12)
	Book (2)	Software (4)	Blueprint (3)	Blueprint (10)
	Blueprint (2)	Map (3)	Map (3)	Map (6)
	Humanities/generalist FGs			
	FG 4 (4)	FG 5 (4)	FG 6 (8)	
3 Most helpful metaphors (frequency)	Landscape (2)	Software (3)	Pianist (7)	Pianist (7)
	Recipe (2)	Landscape (2)	Punctuation (3)	Software (5)
	Software (2)		Recipe (3)	Landscape (4)
3 Most misleading metaphors (frequency)	Map (2)	Blueprint (2)	Book (2)	Blueprint (5)
	Memory (1)	Map (1)	Software (2)	Map (3)
	Blueprint (1)	Recipe (1)	Blueprint (1)	Software (2)

participants chose only metaphors that they felt were directly relevant to them personally – for example, several said "I don't play music so I can't relate to the pianist metaphor"; or "I know nothing about architecture so I don't understand this blueprint metaphor". This furthermore reflected a gender bias, with female participants often rejecting the computer metaphors as "not talking to me because I understand nothing about computing," and instead relating more positively to the playing/ cooking metaphor as "more convincing". We present the views of participants using three major axes of argumentation emanating in the FGs concerning the meanings of the metaphors discussed in relation to what respondents understood about epigenetics: accurate/helpful, static/dynamic, and the problem of agency.

Accurate/helpful

Many participants across the groups echoed the scientists' encoding when selecting the most helpful metaphor as the one they viewed as (scientifically) the most accurate:

> For me the most helpful metaphor is the pianist on the genome's keyboard. Compared to the other metaphors, it really describes the situation accurately, of a general dictionary of the DNA and its different interpretations by the cell system thanks to its epigenetic marks. (Group 3)

For a minority of the genetics students, "accuracy" was the same as "usefulness":

> The epigenetic landscape is the most representative paradigm used by scientists to examine the different forms cells can acquire and how epigenetic modifications are implicated in that process. It is the clearest example and I can reproduce it to others to introduce epigenetics. (Group 2)

In many of the groups there was a discussion about how accurate the metaphor really was, and whether the metaphor needed to be technically accurate or precise (i.e. "true") vs. helpful or insightful. In another group this discussion led to a consensus that sometimes metaphors can be helpful and must be explicated through an actual example.

> Annotation is misleading because annotation changes the meaning of the sentence while epigenetics doesn't change the meaning of the gene, it just amplifies or turns it off.
>
> I mean the protein is always there. The same. The protein is not annotated.
>
> I chose the accent or punctuation because it's really concrete. We use it every day so it makes sense and I can picture it in my head. (Group 2)

Others argued that when a metaphor is too accurate it becomes less helpful as a metaphor:

> P1: Genetic memory, I wouldn't really call it a metaphor, because that's what actually happens. It's too accurate to serve as a good metaphor.
>
> P2: The pianist is a good metaphor but that doesn't mean it's a true metaphor.
>
> P1: Is it really that different, two pianists that play the same musical piece?
>
> P3: But isn't it the point of the metaphor to make it simple to people …
>
> P2: What would be a true metaphor?
>
> P4: The landscape is better. Yeah you can explain more things. … You don't know. But you don't lie about it.
>
> P2: the best metaphor is able to describe the general aspect. I think the punctuation does it best. In epigenetics there are different combinations of modifications. You don't easily get this idea with punctuation. In epigenetics you have histone methylation, DNA methylation and so on … (Group 2)

Genetics students who discussed the accuracy of the metaphor vs. its practical value, pointed out that even though they were already familiar with Waddington and the landscape metaphor, it was not selected by the majority as very helpful.

Static/dynamic

An important element in the meaning of the metaphor, according to many participants, was its dynamic connotation. Discussion revealed that the overall conception of the DNA genome was static (unchanged) as compared to the dynamic epigenome. Hence, *music* and *cookbook* metaphors worked better than the *landscape* metaphor for most of the respondents:

> I think we all globally agreed that the pianist was the most helpful metaphor because it is dynamic, and epigenetics is something that is changing. (Group 3)

> The architect is definitely wrong for me – it's very static. (Group 4)
> The architects' blueprint for me was the least helpful – epigenetic modifications are more dynamic than that. (Group 2)
> The highlighting is really something fixed. But with epigenetics, when a gene is activated or deactivated this is reversible. (Group 2)

The following exchange from group 4 articulates the metaphorical dynamism of the *recipe* metaphor in an original way:

P1:	I prefer the recipe metaphor in that it stresses such a bare, I mean quotidian, [activity], we cook not because we want to express ourselves but because we need to, right? So. P2: That's because you're not French
[group laughing]	
P1:	That's true. One reason I guess why I like the cookbook is that it kind of merges the book and the highlighting of the text, but I actually also think of recipes, you know, before there were cookbooks, recipes were oral. The way recipes would get transmitted it's an oral transmission. And so it both remains the same and it changes over time. (Group 4)

Other, minority views articulated the idiosyncrasy of what it means to be dynamic:

> The recipe is something static. It is just written. The metaphor doesn't mention something dynamic. Whereas in the landscape metaphor you see the ball that's falling, right? And it seems to me it's one of the only metaphors that take the process of … (Group 2)
> I like the accent and punctuation metaphor because accents and punctuation can change the meaning of the sentence but also the rest of the story! (Group 5)
> If our genome is in the cards we get, epigenome is the way the player is playing, the hand you have is not that important, more important is how you play your cards. (Group 1)

The following minority view (from a genetics student) that considered the genome as dynamic (in an evolutionary and phylogenetic perspective, rather than in the organism) highlighted and contrasted the common view shared by the rest of the respondents:

> It seems to me that the genome also shows dynamism in evolution so it's not just hardware … software/hardware interaction is more a master/slave relationship. That seems dubious in a genetics setting where genome and epigenome interact together very tightly with interdependence. (Group 1)

The problem of agency

Several of the metaphors that were preferred because of their perceived accuracy nevertheless raised the question of intentional agency, e.g. music needs a musician, cookbook needs a cook, blueprint needs an architect – this seemed to be problematic and some favored agent-less metaphors**:**

P1: I think that the recipe, I found it the most useful one, because it provides all of the, as far as I can understand from the movie, all the aspects of epigenetics, with the environment, with the static and non-static elements inside the interpretation, and the impact of the cook in preparation, the outcome of the recipe, so …
P2: Who's the cook?
P1: The cook is the environment in this case. I believe.
P2: So, I agree with you, I like the metaphor of the pianist and the recipe, but there is a problem of the being behind, the musician and the cook, and I think it is better to try and explain this without reference to someone who is, who would be interpreting …
P1: So, what is your preferred metaphor?
P3: So, I think the landscape. It explains the different mechanisms without someone interpreting anything.
P1: So, on the one hand you don't want to introduce so much the notion of an intentional agent concept, but on the other hand what epigenetics actually does is to say that decisions actually make a difference in life, right? So it does introduce the intentional agent a little bit, right? We don't want to overstate it. But the landscape metaphor for me was too static. (Group 4)

Discussion and conclusions

Epigenetics is an emerging scientific discipline in search of new metaphors. Our study explored how scientists and lay people confront and negotiate this liminality – how an "old" set of metaphors such as *code*, *blueprint* and *book* are being replaced by novel metaphors that still have no clear scientific, objective target. With a relatively small number of respondents, our findings cannot be generalized. Nevertheless, this exploratory study provides us with several intriguing signals regarding the framing and decoding of the epigenetic message, that can serve as the basis for future research. While previous studies of epigenetic metaphors focused on scientific and popular writing, our study also examined the reception of epigenetic metaphors by different audiences. Previous studies, that centered on the popular scientific and media encoding of epigenetic metaphors, addressed gaps and discrepancies in that encoding – for example, gaps between source and target domains (Nerlich and Hellsten 2004, 2009; Hellsten and Nerlich 2011; Stelmach and Nerlich 2015). Our study confronts, for the first time, these perceived challenges in encoding with the experiences of the decoders. It adds a novel comparison between the production (encoding) and reception (decoding), thus addressing the challenges of communicating about a new and controversial field to lay audiences in a setting outside the Anglophone countries.

It is intriguing that despite the educational heterogeneity of our respondents, we found evidence for a dominant decoding position: The *pianist* was considered the most meaningful and helpful metaphor across all groups, consistent with the preferred music metaphor of epigeneticists. In addition, *software*, *blueprint* and *map* were regarded as the most misleading metaphors across all groups, in line with the same metaphors being rejected by epigeneticists. In this context, the documentary film (where the *pianist/music* metaphor features prominently) arguably primed and influenced participants, who borrowed the metaphors articulated by the scientists, decoding them in a very similar way to how they were encoded. Such dominant decoding reflected, as we saw in the FGs discussions, similar criteria held by the scientists and the lay groups for selecting preferred metaphors. These common criteria were: “accuracy”, including an emphasis on dynamism (in contrast to the relatively static/unchanging genome) and “usefulness” in communicating the message. However, there were also findings that presented a negotiated position: for example, the metaphor of *cooking*, although supported by the scientists and portraying the criteria of dynamism and accuracy, did not (unlike *music* playing) come up as one of the three most meaningful and useful metaphors among lay participants. In addition, *memory* and *software* – two metaphors rejected by the epigenetics researchers – were selected as the most meaningful and helpful by the genetics/medicine students as well as the humanities/generalist students. Other more creative examples of negotiation were reflected in new metaphors proposed by lay participants, such as card-playing. We did not find any argumentation or metaphorizing contradicting the premises and messages of epigenetics in a manner that might represent oppositional decoding.

Studies of science communication have emphasized the importance of the communicator’s segmenting target groups and taking their interpretative frames into account (Brossard and Lewenstein 2009). Our study shows that with effective priming (e.g. the ARTE documentary film), different audiences present quite similar knowledge and decoding, while also sustaining a diversity of interpretations. A future study might try to “prime” different groups with different priming material that uses different metaphors and then confront these in focus group discussions. In terms of science communication, our findings show that “framing the message” may be just as important as providing the facts. In general, science communication is varied, eclectic and without effective priming; the fact that our study did involve priming in the form of the ARTE film provided unique circumstances, whose results do not contradict the challenges of science communication in general. The narrow emphasis of the traditional “deficit approach” on filling out knowledge gaps through facts should be thus complemented by an emphasis on the metaphorical framing of such knowledge and its embeddedness in broader, popular narratives which are often built on easy-to-understand contrasts (Bubela *et al*. 2009). The more physical and biological language of *chromatin* as the dynamic wrapping of DNA was rarely mentioned by our respondents, who preferred more catchy metaphors like the *pianist*. The catchiness or “usefulness” of the preferred metaphors was also framed by the lay respondents in relation to previous grand and pre-deterministic genomic metaphors (such as the “book of life”). Rather than the metaphors of the *switch* and the *mark/tag* that Stelmach and Nerlich (2015) collected from UK newspapers, the preferred metaphor across all our lay groups was the *pianist*. Not only does this metaphor highlight the dynamic nature of epigenetics over the more static perspective of the genome as a *book*, *map* or *blueprint*, it also apparently foregrounds hopes of control over and regulation of human physical and social health. The public appeal of the new set of metaphors (and indeed of epigenetics as a new science) seems to stem from the potential promise to have power over our genes, the power to modify their activity, turning them on and off, and "hoping we can pray our way out of faulty genes" (epigenetics Professor Edith Heard in an interview to The Guardian[1]).

What can the findings teach us about the link between knowledge and metaphor evaluation, and about the helpfulness of metaphors for understanding? Despite their different educational orientations, after watching the film our lay respondents expressed relatively similar knowledge about epigenetics and overall similar interpretations of the meaningfulness of metaphors, especially regarding "the pianist". Why was the epigenetic metaphor of the pianist the most popular? It could be generally argued that this metaphor foregrounds hopes of control and regulation, but this requires further empirical support. Moreover, this argument raises the question of why the pianist was selected despite implying agency, the criterion considered as problematic by the participants. This paradox may be partially answered by recalling that the music metaphor and the pianist were present throughout the film we showed the participants; not just once or twice, but a constant mention which arguably contributed to an even more effective priming. More concretely, the metaphor of the pianist referred to daily life. While this could also be said about using recipes to cook meals or using maps (which may be even more popular and mundane activities than playing the piano), cooking and using maps might also reflect a gender bias, whereas music does not. Moreover, even novices can appreciate differences in the way a piece of music is played, whereas it might be less obvious that differences in tastes are due to the cook rather than to the ingredients.[2]

Moreover, our findings also show that the consensus on the *pianist* metaphor is just the "tip of the iceberg," underpinned by a diversity of views and images, amongst scientists as well as lay people. The analysis of the pianist metaphor thus needs to be complemented by reflecting on the fact that despite the priming of the audience, other metaphors such as the "memory" and "software" metaphors, which had been rejected by experts in epigenetics, were still selected and deemed meaningful by lay participants of the study, reminding us of the challenges of science communication highlighted in the introduction.

One of the major difficulties illustrated by our respondents was the complex inevitability of explaining the epigenome in terms of the genome. The respondents' knowledge about genetics was often Mendelian, affixing genes with determined physical traits and predispositions for disease that are inherited by offspring. While partially correct, this understanding may also inhibit explanations of epigenetics. The diversity in opinions amongst epigeneticists has already been demonstrated in relation to the boundaries and politics of the field of epigenetics in general, whose practitioners were classified into three groups based on the claims they make about the impact and future of their field: champions, those who take the middle ground, and skeptics (Tolwinski 2013). Our "encoding" findings highlighted that the epigenetics experts are aware of the difficulties in choosing metaphors and how they might be interpreted. They clearly voiced these issues as challenges in science communication, communication that can be difficult because of the bias of technical specialization. Indeed, Waddington himself referred to the fact that the landscape metaphor could be understood in different ways. Our findings complement the variance in discourse about epigenetics and future research could investigate the inter-correlation between how scientists see the future of their field and which metaphors they prefer. The metaphorical diversity we found also suggests a far more complex and contested trajectory for the field, one that may or may not support anti-deterministic views.

It would have been intriguing to discuss whether there are any national or cultural factors that may differentiate the production and reception of epigenetic metaphors in the context of our French respondents. While our respondents mentioned Lamarck when evoking the inheritance of acquired features through cross-generation epigenetic persistence, this was in passing and did not appear to be specifically "French"; indeed, Lamarckism has had a more tenacious influence in other countries outside the dominant reach of Euro-American genetics, such as the Soviet Union/Russia (Kolchinsky *et al*. 2017) and Brazil (Hochman, Lima, and Maio 2010). In addition, some of our bio-sciences students were Anglo-Saxons who came to Paris to study. Our findings therefore signal a de-differentiation of the popular reception of epigenetic metaphors, possibly connected to the broader Euro-American shift in social representation from grand, pre-determined genomic metaphors of the "book of life" type, to more modest and plastic metaphors. In sum, for all their problems, metaphors are indispensable tools for both practicing and communicating science. This exploratory study illustrates major foci and factors regarding the framing of the epigenetic message that can serve as a basis for future research.

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Notes

1. Edith Heard: “We can’t undo what our parents have given us in terms of our genes” By Catherine de Lange, *The Guardian* 23 Jun 2013. https://www.theguardian.com/science/2013/jun/23/rational-heroes-edith-heard-epigenetics. Last accessed 6 April 2018.
2. It is telling that there are many music metaphors in communication about epigenetics, such as “Epigenome: The symphony in your cells”; https://www.nature.com/news/epigenome-the-symphony-in-your-cells-1.16955, or in recent books such as “La symphonie du vivant”, https://www.symphonieduvivant.com/r%C3%A9sum%C3%A9-du-livre/.

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Appendix 1. The focus group questionnaire and interview guide

Examples of epigenetics		
Which of the following study topics is an actual example of the science of epigenetics: (Y/N)	Y	N
1. the connection between the increase in plastics in our environment and rising obesity rate		
2. why one twin may develop breast cancer but not the other twin		
3. the connection between eating and development (for example the queen bee)		
4. the connection between food deprivation in pregnancy and diabetes		
5. the connection between animal experimentation and abuse of animals		
6. how eye color is inherited		
7. how social class may affect life prospects		
8. the newborn baby of a body builder is likely to have more muscles than the newborn baby of someone who is not		
9. curing Down's syndrome		
10. the connection between academic studies and level of income		

For each of the following metaphors designed to explain the science of epigenetics, which is helpful or misleading in your view? Write down a grade between 1 and 10 (1 – not at all, 10 – totally). If the metaphor is not relevant, write N/A.

Metaphors of epigenetics	Helpful	Misleading
The pianist on the genome's keyboard (how interpreting the **musical score** can change the music)		
A nuclear **map** of chemical switches		
Genetic **Memory**: If something from the outside, like nutrition or stress, can affect the inside of our bodies, genes can remember it. Such genetic memories alter how genes run our bodies' internal workings		
If the genome is the **Book of Life**, the epigenome is how a specific cell type marks it up with **highlighters**		
The Epigenetic **landscape**		
The recipe – if the genome is a cookbook, epigenetics is the annotated recipe, different cooks will prepare the recipe differently		
An architect's blueprint that contains the instructions for constructing a building		
The computer software necessary to function together with the genetic hardware		
The accents or punctuation that change the meaning of the words or the sentence		

- For the metaphor you graded as most helpful, please explain why it is the most helpful, for you, in comparison to the others.
- For the metaphor you graded as the most misleading (or least helpful), please explain why it was the most misleading, for you, in comparison to the others.

- Can you suggest another metaphor that caught your attention in the film, or more broadly in the media, and you think is helpful for understanding epigenetics?

Following the discussion

How did the discussion influence your views and arguments about the most helpful and the most misleading metaphors?

Would you like to share any additional comments about the film or the focus group discussion?

Thank you!