

Communicating genomic complexity

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Abstract

The field of public understanding of science has long rejected the ‘deficit model’, according to which the aim of science communication is to bring the views of the public into line with those of experts. However, the shortcomings of public understanding of genetics and genomics remain the focus of considerable concern in the history and philosophy of biology. I argue that these concerns should not be tarred with the same brush as the deficit model. They do not result from privileging the representations of scientific experts, but rather from substantive concerns about the scientific content that is being communicated, and with ‘deficits’ in both expert and public understanding. History and philosophy of biology and public understanding of genetics research need to be integrated to yield a deeper understanding of the problem of communicating—and formulating—the complexity of genetics and genomics.

Introduction

A large body of research documents limited public understanding of the complexity revealed by contemporary genetic and genomic research. A recent nationally representative survey of adults in the United States found that 76% incorrectly believed that “single genes directly control specific human behaviors” (Christensen et al. (2010), 470). Findings like this suggest that there is a problem with public understanding of genetics and genomics, and historians and philosophers of science have frequently argued as much (e.g. Nelkin and Linde 1995, Oyama 1985, Keller 1995). However, researchers who specialize in studying the public understanding of genomics disagree, arguing instead that laypersons have “a complex, informed understanding of genetic research, albeit a non-technical one” (Bates et al. 2005, p 331). The lack of a technically correct understanding is not enough to show that there is a problem: “Just because the

public does not have a highly technical background does not preclude them from making sensible judgments about genetic science and genetic technology. A person can drive a car perfectly well without understanding the physics of internal combustion or body shell design. These drivers are also allowed to express opinions on where roads should go, what the speed limit should be, and the relative importance of pollution, accidents, and noise to automotive policy” (Bates 2005, p 61). These remarks reflect a long-standing consensus amongst science communication researchers that the adequacy of public understanding of science cannot be reduced simply to the degree to which laypersons agree with scientific experts. Here I argue that ideas from these two research fields—history and philosophy of science and public understanding of science—can be integrated to yield a deeper understanding of the problem of communicating genetic and genomic complexity.

I will not address in any depth here the exact sense in which contemporary genetics and molecular biology is a complex systems science (Griffiths and Stotz 2013). Instead, consider only the nematode worm *C. elegans*, a tiny organism with around 13000 genes and 1000 cells, of which 300 are neurons, deliberately chosen as a simple and tractable model organism in which to elucidate the basic principles by which genes give rise to phenotypes. As Kenneth Schaffner (2016) has pointed out, in the worm we see that many genes are involved in the development of each neuron; that many neurons are involved in each behaviour, and that these circuits frequently overlap; that any one gene is involved in the genesis of many neurons and can affect many behaviours, as can any one neuron; that the process by which genes act to wire together the neurons is stochastic rather than deterministic; and that the worm's environment has a large influence on both the development of neural networks and the behaviour produced by those networks. This is a far cry from discovering a 'gay gene' or a 'gene for adultery' and yet it is unlikely, to say the least, that the genetics of these human phenotypes is any less complex than that of feeding behaviour in the worm.

Public understanding of science

A defining moment in the emergence of public understanding of science as an academic field was the Bodmer Report, *The Public Understanding of Science*, released in 1985 by the Royal Society (Bodmer 1985). The report's focus on improving 'scientific literacy' carried the implication that the public was deficient in scientific knowledge and understanding (Durant et al. 2000). Public understanding of science has traditionally been measured using surveys of rep-

resentative samples of the general population that assess factual scientific knowledge and self-declared attitudes towards science. They consistently reveal that, "If modern science is our culture's greatest achievement, then it is one of which most members of our culture are very largely ignorant" (Durant et al. 1989, p 13).

The idea of the 'deficit model' came to prominence in the early 1990s, and the model was criticised at the same time as being explicitly formulated (Wynne 1991, Ziman 1991, Silverstone 1991). These influential critiques of the deficit model make several points. The model misrepresents science, portraying it as an unproblematic body of knowledge. The deficit model misrepresents the communication process by treating the audience as passive recipients of scientific information. The standard of success for science communication in this model is the extent to which public understanding mirrors expert scientific understanding. The model "isolates science from contexts that give it public significance" (Gross 1994, p 7) and ignores the fact that the public can access other sources of information, not just through the media, but through local knowledge, practical understanding and common sense (Silverstone 1991). Additionally, the deficit model has been criticised for overlooking the fact that "a great deal of scientific knowledge is both remote from and largely irrelevant to everyday life" (Durant et al. 1992, p 162). Rather than representing a deficiency, public ignorance of science may reflect a sensible allocation of limited time and cognitive resources.

These and other criticisms of the deficit model created pressure for new forms of empirical research into public understanding of science. Mass surveys predominantly

measure factual knowledge about science and neglect other information that contributes to the public's comprehension of specific issues (Bates et al. 2005, Bates 2005). These surveys pay little attention as to why people might want to understand science, and what they may wish to know about science (Turney 1995). These issues can be investigated using more qualitative methods, such as participant observation, longitudinal panel interviews, structured in-depth interviews, and focus groups. A large body of research of this kind now exists, a significant proportion of which is concerned with the public understanding of genetics in particular. Meanwhile, the deficit model has been replaced by a 'constructivist' model in which laypersons construct their knowledge of science from multiple sources in a way driven by their own needs and interests. The public does not just 'soak up the facts' from scientists or the media, "but retain a healthy skepticism about the source of expert knowledge as well as about that knowledge itself" (Cunningham-Burley 2003). While they may not have technical knowledge of genetics, "the public articulates complex understandings of genetic research" (Bates et al. 2005, p 340) drawing on multiple sources of information and understanding.

Historians and philosophers of biology on the public understanding of genetics

The controversy surrounding the very idea that public understanding of science is deficient has not had much impact on the history and philosophy of biology. In this field it is assumed that inadequate understandings of genes and gene action are common, and discussion centres on how to improve the

situation (e.g. Oyama 2000a, Keller 2000, Morange 2001, Moss 2003, Kitcher 2003, Robert 2004). The distinguished historian of molecular biology Michel Morange even titled a book *The Misunderstood Gene*. But whereas the deficit model is concerned with the gap between scientific understanding and public understanding, these authors are concerned with deficient understandings shared by scientists and publics alike. This deficient understanding is *successfully* communicated to the public.

The dominant theme in this literature is the need to combat overly simple views of genes and gene action, commonly referred to as 'genetic determinism'. It is important to note that this label is used rather differently from the way it is used in public understanding of genetics. 'Genetic determinism' in history and philosophy of biology is the view that the relationship between genotype and phenotype is insensitive to variation in the developmental environment, at least within the normal range of such variation (Kitcher 2003). In the public understanding of genetics literature, however, 'genetic determinism' refers to the much stronger view that a genotype inevitably destines its bearer to a phenotype (Condit et al. 1998, Condit 1999b esp. 99ff). Thus, while rhetorician Leah Ceccarelli describes the "*nondeterminist* and overly optimistic belief that we can easily change our fate with a simple alteration of our genetic blueprint" (Ceccarelli 2004, p 93, italics added), authors in history and philosophy of biology would see this as belief in genetic *determinism*, because it anticipates that the results of such intervention will be predictable, rather than dependent on details of the genomic and environmental context. The stronger version of genetic determinism might better be called

‘genetic fatalism’.¹ Determinists believe that the totality of causal factors at a given time uniquely determines the future. If some of those factors were to change, however, the future would likely change too. In contrast, fatalists believe that the future is determined so that no changes in the present can affect it: if you see Death in the marketplace and ride to Damascus to escape him, Death will meet you in Damascus. Public understanding of science research suggests that the public are not genetic fatalists (Condit 1999a, Condit 1999b), but they may still be genetic determinists.

Genetic determinism is a matter of degree, in the sense that the pattern of interaction between genetic and environmental factors may be genetically deterministic in some cases and not others (Kitcher 2003). It is relatively uncontroversial to claim that the most practical prospect for treating some currently incurable heritable diseases is gene therapy, although that is a genetic determinist view of those diseases. But it is extremely controversial to argue that no practical environmental intervention can eliminate the differences in educational outcomes between ethnic groups in developed countries, or greatly alter the proportion of men and women who achieve prominence in the sciences. So the objection is not to genetic determinism *per se*, but to a blanket presumption of genetic determinism for a wide range of human characteristics.

Finally, it is important to note that the alternative to genetic determinism for authors in the history and philosophy of biology is not an equally implausible environmental determinism but the ‘interaction-

ist’ view that for many and perhaps most phenotypes there are both genetic and non-genetic factors that are practical sites of intervention to change those phenotypes (Kitcher 2003).

An important theme in these critiques of genetic determinism is the effect of the dominant informational metaphors used both within biology and in popular presentations of biology. The current dominance of these metaphors cannot be overstated (Nelkin and Lindee 1995, Condit 1999b, Griffiths 2001). There is nothing unusual about the following journalistic summary of what we have learnt since Crick and Watson:

An organism’s physiology and behaviour are dictated largely by its genes. And those genes are merely repositories of information written in a surprisingly similar manner to the one that computer scientists have devised for the storage and transmission of other information ... (*Economist* 1999, p 97).

Historians have examined how informational metaphors entered biology from a specific cultural milieu in the 1940s and early 1950s (Keller 1995, Kay 2000). The resulting metaphorical landscape actively shaped the way in which biology developed from that time onwards. Historians and philosophers have suggested that the metaphorical landscape of information is not adequate to represent what contemporary biology has accomplished. It introduces some systematic biases into both popular and scientific understanding of those accomplishments of modern biology (Sarkar 1996, Robert 2001, Griffiths 2006). The consequences of uncritical acceptance of informational descriptions of genomics like that quoted above are not restricted to the various extra-scientific publics, but very likely affect biology itself

¹ Richard Dawkins calls it genetic Calvinism (Dawkins, R. 1982, *The Extended Phenotype: The long reach of the gene*, Freeman, San Francisco., p 11).

through a feedback relation between popular science and the future direction of science whose importance has long been recognized (Fleck et al. 1981 [1935]).

Two approaches to analyzing metaphors in genetics and genomics

A number of authors have advocated the replacement of the metaphor of the genome as blueprint in public discourse with the metaphor of the genome as recipe (Hubbard and Wald 1993, Nelkin and Lindee 1995). They have suggested that the recipe metaphor will produce a less deterministic understanding of gene action. This prediction has been empirically tested and rejected by Condit and collaborators (Condit and Condit 2001, Condit et al. 2002). They show that both recipe and blueprint metaphors activate a range of associations in audiences more diverse than those anticipated by advocates of the recipe metaphor. Some subjects understand the ‘recipe’ metaphor *more* deterministically than the blueprint metaphor; others understand the two metaphors primarily via their existing religious belief system, so that the main issue for them becomes the match between each metaphor and their image of the Creator. Condit et al.’s textual analysis of the actual use of the recipe metaphor in popular science writing reveals that it is deployed in the context of an existing understanding of genetic causation, and in association with a range of other metaphors, in such a way that it becomes merely another way to express the existing understanding of what genes do in the construction of phenotypes. A focus group study produced a similar result—the recipe metaphor was interpreted in such a way as to remove the associations intended by its advocates. Condit and collaborators frame their results as support for a more adequate

theory of metaphor and its effects, adapting a framework due to Joseph Stern in which a large range of possible associations is filtered by context and by the audience to produce a particular interpretation of a metaphor. This implies that the use of metaphor to induce a desired understanding would require an understanding of the specific audience, and control over many aspects of the act of communication.

These studies drive home the lesson that, “the critical analysis of metaphors cannot successfully be conducted in an off-hand fashion that is inattentive to the workings of language and metaphor.” (Condit and Condit 2001, p 36) Similar critiques could surely be made of other claims advanced by history and philosophy of biology authors, such as the claim that the application to the genome of the common-sense semantic notion of information (‘meaning’) promotes genetic determinism (Oyama 2000b, Griffiths 2006). This is an important reality check for the many authors in history and philosophy of biology who have advocated ‘refiguring life’ (Keller 1995). Like the deficit model, the history and philosophy of biology literature has neglected the fact that audiences actively process information to construct autonomous understandings of science, rather than merely mirroring more or less imperfectly the understandings offered to them.

When viewed as an attempt to forge tools with which to communicate scientific content, the history and philosophy of biology literature looks naïve. But before giving up on that literature we should realise that this is not the only aim of most authors in history and philosophy of biology. They are also, and perhaps primarily, trying to find metaphors that embody an adequate generalized under-

standing of the ‘lessons’ and expectations to be derived from current biology. Unlike specific research findings, such broad visions of science do not pre-exist their formulation in more or less figurative language. Reading the literature on the recipe metaphor from this alternative perspective reveals some shortcomings in the analysis by Condit and her collaborators. Those authors lay great stress on the gendering of the two competing metaphors (blueprint as male, recipe as female): “when the scale is held constant (industrial baking is compared to large buildings or a homebuilt cabin is compared to homemade bread), the similarities between the metaphors are most evident. Thus, blueprint and recipe metaphors differ primarily through their gendering...” (Condit et al. 2002, p 306). As for the thought that the recipe metaphor will help combat determinism, “Perhaps the social critics who recommend the recipe metaphor, most of whom have been female, see the recipe as more passive and amenable to individual control because, as females who have been conditioned to traditional mores, they may be more familiar with recipes than blueprints” (Condit et al. 2002, p 306).

But whilst the gendering of the recipe metaphor is likely of importance for its reception by some audiences, it is not a plausible view of the motives of its advocates. The recipe metaphor was first introduced as an alternative to the blueprint metaphor by the ethologist Patrick Bateson in a popular talk for the BBC in the early 1970s (Bateson, personal communication) and in a scientific paper on behavioral development written around the same time (Bateson 1976). It was taken up by Richard Dawkins and most later uses can be traced back to his extended discussion of the recipe metaphor in *The Blind*

Watchmaker (Dawkins 1986, esp. 295–6). Thus, whilst Condit and her collaborators correctly note the ‘homeliness’ of the recipe metaphor as one of its distinctive rhetorical features, this is more likely to reflect a tradition of ‘homely’ metaphors in ethology (e.g. the ‘flush-toilet model’ of Lorenz 1950, p 256) than its gendered origin.

Condit and collaborators identify the errors that result from neglecting the role of the audience in interpreting the recipe metaphor, but they misunderstand the intentions of those who produced this metaphor. Those authors used the metaphor to formulate their own understanding of genomics as much as to communicate it to a wider audience. They were concerned with the difference between a description of the final product (blueprint) and a set of instructions for making a product (recipe). They believed that in certain key respects the genome-phenotype relationship is strongly disanalogous to the first and more closely analogous to the second. Condit and collaborators have criticised this claim by identifying examples in which the claimed disanalogy fails to hold. Thus, for example, Bateson and Dawkins both emphasised the fact that, whereas the elements of a blueprint each correspond to an element in the final product, the instructions in a recipe do not. Condit et al. find this point in later authors and reply with a counterexample: the individual elements in a salad recipe *do* correspond to elements in the salad (Condit et al. 2002, p 306). They also notice that builders deviate from blueprints in ways that reflect the resources and materials available to them, so that contextual factors affect outcomes just as they do with recipes. They suggest that, “the relative appeal of the recipe metaphor lies not in an escape from deterministic language but in its associations with the per-

sonal rather than industrial, the nurturing rather than controlling, and with creative individual action. Recipes come from the realm of the familiar, the personal, and the small, rather than the commercial and the large” (Condit and Condit 2001, p 32). But this is not the appeal the recipe metaphor had to its originators.

In his use of the recipe metaphor, Bateson was trying to convey a specific concern about appeals to information in the explanation of behaviour that can be traced back in his own research tradition to the late 1960s: “although the idea that behavior patterns are ‘blueprinted’ or ‘encoded’ in the genome is a perfectly appropriate and instructive way of talking about certain problems of genetics and evolution, it does not in any way deal with the kinds of questions about behavioral development to which it is so often applied” (Lehrman 1970, p 35). The relationship between genes and behaviour is mediated by chemical properties such as the stereochemical affinities of gene products, or their diffusion rates. Bateson chose the metaphor of a recipe because it involves the same kind of causal interactions as development—chemical ones. The metaphor of chemical engineering as opposed to mechanical engineering would have conveyed his meaning just as well, but the source domain of that metaphor would have been less familiar to his audience. Similar criticisms of the blueprint metaphor are readily found in the writings of developmental biologists generally, not only in those concerned with behavioral development in particular. Thus, in ‘Metaphors and the role of the genes in development’ H. Frederick Nijhout, best known for his work on morphogenesis in butterflies, writes that “[t]he simplest and also the only strictly cor-

rect view of the function of genes is that they supply cells, and ultimately organisms, with chemical materials” (Nijhout 1990, p 444). Nijhout does not use the word ‘recipe’ but it is on the tip of his tongue: protein-coding sequences in the genome are a list of ingredients. So the recipe metaphor was intended, not only as a device for popularization, but as a vision of developmental biology and one intended to be taken as seriously as William Harvey’s analogy between the heart and a pump. Critics and defenders (e.g. Rosenberg 2006) of the blueprint metaphor were not simply disputing which metaphor will best communicate to the public their shared vision of biology. They were also disputing which vision is correct, and hence which should be communicated.

In this section, I have suggested that public understanding of genetics and history and philosophy of biology are pursuing significantly different projects when they evaluate genetic metaphors. Public understanding of genetics emphasizes the impact of metaphors on diverse audiences and does not usually see the chosen metaphor as partly constituting the science to be communicated (but see Bucchi 2004). In contrast, history and philosophy of biology is concerned with competing visions of science embodied in metaphor. It is concerned with the correct ‘big picture’ of biology to communicate to the public, and has paid too little attention to the active role of the public in constructing their own ‘big picture’, a process in which the material offered to them by science communicators will be only one of many influences. But although distinct, these projects have a great deal to offer to one another. Public understanding of genetics could usefully integrate the idea that what needs to be communicated is often

a ‘vision’ of biology which cannot readily be separated from the figurative language used to express it (Stotz and Griffiths 2008). Conversely, in so far as history and philosophy of biology wishes to make a contribution to improving public understanding, it will have to pay attention to research in public understanding of genetics.

What should the standard of success be for science communication?

We have seen that rejection of the deficit model led to an emphasis on the process by which audiences construct their own, autonomous understandings of biology using ideas from multiple sources. A substantial body of empirical research has documented that this is a more adequate model of what public understanding of science consists in than viewing it as the more or less successful transmission of a message. The constructivist model also suggests a standard by which public understanding is to be assessed: it is adequate to the extent that it allows people to function effectively in situations in which they have to deal with the biological sciences. These include personal choices, such as whether to take a genetic test or consume a GM product, and collective choices, such as whether to support the California referendum proposition to fund stem cell research. Using this standard, the ‘best’ understanding may in some cases be no understanding. The concept of ‘rational ignorance’ suggests that laypersons do not assimilate some biological information for the same reason biologists do not assimilate information they encounter about derivative contract pricing—they have more pressing matters to think about.

History and philosophy of biology has shown little interest in this aspect of science communication research. It has been concerned with how best to understand biology on the assumption that understanding it *is* important. This suggests that if the two fields are to enter into a productive dialogue they will need to distinguish two issues. The first is whether the constructivist standard is the correct way to evaluate the public understanding of biology. The second is whether current understandings are adequate when compared to this standard. Most public understanding of genetics research to date has focused on the first issue, documenting that the public “processes messages about genetic research complexly and critically” (Bates 2005, p 47). However, demonstrating that laypersons have *autonomous* understandings is not the same thing as demonstrating that those understandings are *functional* for the people that create them. No doubt a focus-group study in early 20th century Europe would have shown ordinary citizens processing scientific information about race and heredity in a complex way and in the light of existing ideas derived from folk tradition, popular culture and personal experience, to produce autonomous understandings. Nevertheless, the understandings they created were disastrous, certainly for their societies collectively, and often for themselves individually. Thus, whilst the critics of genetic determinism in history and philosophy of biology would benefit from taking on board the sophisticated model of public understanding that has been generated by the past twenty years of work in public understanding of genetics, this does not invalidate their continuing concerns about deficiencies in public understanding.

Conclusion

History and philosophy of biology and public understanding of genetics can and should learn from one another. History and philosophy of biology does not simply recapitulate the errors of the ‘deficit model’ because it does not believe that the aim of communicating biology is to bring public understanding of biology into line with that of biologists themselves. However, work in history and philosophy of biology *has* often assumed another aspect of the deficit model, namely that improving public understanding is a matter of ‘transmitting’ the right thing to the public, even if the right thing consists of contestable visions of contemporary biology (Stotz and Griffiths 2008). Since the amelioration of public understanding is an explicit aim of many authors in history and philosophy of biology, there is an urgent need for them to assimilate the sophisticated approaches that have been generated by a quarter-century of work in public understanding of science.

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