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A Pragmatic Approach to Scientific Change: Transfer, Alignment, Influence

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Abstract

I propose an approach that expands philosophical views of scientific change, on the basis of an analysis of contemporary biomedical research and recent developments in the philosophy of scientific change. Focusing on the establishment of the exposome in epidemiology as a case study and the role of data as a context for contrasting views on change, I discuss change at conceptual, methodological, material, and social levels of biomedical epistemology. Available models of change provide key resources to discuss this type of change, but I present the need for an approach that models *transfer*, *alignment*, and *influence* as key processes of change. I develop this as a *pragmatic* approach to scientific change, where processes might change substantially depending on specific circumstances, thus contributing to and complementing the debate on a crucial epistemological issue.

Keywords:

Scientific Change; Big data; Paradigms; Exposome; Epidemiology; Postgenomics.

1 Introduction

Scientific change has been one of the main topics of discussion in philosophy of science in connection to several debates on issues including progress, discovery, realism, reductionism, etc. But change is also at the centre of attention in various other areas and disciplines, from the arts to political science, from fashion to the economy and media. This centrality is especially evident in discussions on technology, where for instance the concept of industrial revolution is traditionally used to connect technological changes and scientific, societal, economic, cultural shifts. In recent years, the connection has become more prominent in relation to the increasing use and cultural importance of consumer and digital technologies – n discussions influenced by the high-tech and computing sector, new concepts and phrases are used to refer to changes that revolutionise an industry, if not society as a whole. In turn, these changes tend to be discussed as highly positive phenomena that should be the end goal of societal endeavours. Scientific research is often a source of technological innovations and is thus used as a reference for the type and level of change strived for in this context. At the same time, the sciences are increasingly receivers of technological innovations developed in the technology sector, and the typical wording of the technology industry has started to be used to discuss the ways in which science can and should innovate.

In this paper, I want to contribute to these discussions by introducing a *pragmatic* approach to scientific change, which explains change as a result of processes of *transfer*, *alignment*, and *influence*. This is a contribution to the philosophical debate on change, where several aspects of processes of transfer, alignment, and influence have been discussed in recent contributions, but have not been integrated in a specific approach or model of scientific change. Developing the approach in pragmatic terms entails looking at scientific change as a phenomenon where these processes might change substantially, depending on specific circumstances and pragmatic constraints, thus leading to a picture of change that is dynamic and context-dependent. The approach is thus also a complement to more traditional models of scientific change, which are clearly helpful when it comes to understanding novelty in several cases of change, but are increasingly difficult to apply to contemporary science (Kuhn, 1962; Thagard, 1993; Kitcher, 1995). Finally, the pragmatic approach is a contribution to discussions on change at the intersection of science and technology, which I address by focusing on data as primary context for contrasting views on change and innovation. Crucial philosophical work has recently contributed to understanding the epistemic role of data in the sciences (Ratti, 2020; Nickles, 2020; Leonelli, 2020), but has not been developed into a comprehensive picture of the role that data play in eliciting or preventing change.

To bring these contributions to bear on scientific practice, I ground my analysis with a case study of contemporary change in epidemiology: the 'exposome'. The exposome emerged as an area of focus in epidemiology in the early 2000s, as a new way of conceptualising exposure and moving beyond the genome (Wild, 2005). In the field, the approach is considered highly innovative, to the point that it is usually presented as a new "paradigm" for the study of the relation between health and the environment and the integration of new, diverse, and large volumes of data (Rappaport & Smith, 2010, p. 460). I analyse the type of novelty that the exposome approach has brought and I argue that it should not be simply considered a new and revolutionary paradigm. The novelty of the exposome approach results from the transfer of components from other areas of research, the alignment of methodological, technological, as well as conceptual components, and has led to an increase in the pluralisation of the current epidemiological landscape through processes of influence. I thus use exposome research as a case that shows the processes of change modelled by the pragmatic approach – transfer, alignment, and influence. My analysis of exposome research is primarily based on an empirical study of EXPOsOMICS, a project that applied the exposome approach to the study of exposure and chronic disease between 2012 and 2017 and to which I will make several references throughout this article (Vineis et al., 2017).[1]

The article is structured as follows. I start by introducing the exposome as an emerging approach from the last decade of epidemiology (Sect.2) and I analyse the different senses in which the exposome approach is new (Sect.3). While the exposome approach is a case of scientific change and available models of change help us make sense of this, the overview I develop in Section 4 leaves me with the need to expand these models and complement them with the discussion of different processes of change. To fill in these gaps, I introduce a pragmatic approach to change, which builds on traditional views and contemporary discussions of change, expanding them to identify different types and processes in contemporary science: transfer, alignment, and influence (Sect.5).

2. The exposome: a new framework for exposure in epidemiology

The exposome approach has been introduced in epidemiology as a way to describe and characterise the totality of environmental exposures: all the environmental exposures experienced at any given point in life, at the internal and external level; and all exposures experienced by individuals, from their conception onward. The notion was introduced by Christopher Wild to "complement" the genome in the aftermath of the Human Genome Project, when a number of biomedical scientists started to emphasise the role of the environment for disease aetiology and push for more focus on environmental exposure (Wild, 2005). The study of the exposome was proposed as a way of bringing these propositions together, as well as improve the understanding of the interactions between disease and exposure and the precision of measurements of exposure at different levels (Rappaport & Smith, 2010). Whilst retaining a critical perspective towards genomic approaches, the goal of the approach has been to transfer various genomics techniques to epidemiology and try to do what the genome did for genomics – collect and organise various

[1] This empirical research included qualitative, semi-structured, expert interviews with EXPOsOMICS researchers and a research visit at the Department of Epidemiology and Biostatistics of Imperial College London, where I discussed conceptual, methodological, and social elements of the exposome approach, as well as reviews of project publications and specific studies such as the work from Fiorito and colleagues (Fiorito et al., 2018). I have approached EXPOsOMICS as a case study for the exposome approach and, in turn, exposome research as a case study for the analysis of the epistemology of data and change. These methodological choices are based on views on the role of case studies and scientific practice in philosophy of science (Pietsch, 2016; Meunier, 2019; Morgan, 2019).

ideas and approaches to the study of the relation between environmental exposure and disease (Guttinger & Dupré, 2016).

As such, the exposome approach is often presented as a new "paradigm". Wild himself introduced it to different lines of research, including cancer research (Wild, 2008, 2011, 2012), but the exposome approach has also been discussed as a new paradigm for areas including public health, planetary health, and network science (Juarez et al., 2014; Logan et al., 2018; Vermeulen et al., 2020). Here, the term paradigm is intended to signal dramatic, highly innovative and disruptive change with respect to more traditional approaches in epidemiology (Miller, 2020). Traditionally, epidemiologists have looked at the boundaries between different types of internal and external environments as clearly fixed and the external environment as an indirect source of exposure, thus mostly focusing on external exposure. The exposome approach challenges these views on the basis of an increase in the diversity, scale, and scope of exposure and environment data, introducing the notion of internal environment and conceptualising exposure as a process at the intersection of the boundaries between environments.[2]

More practically, the approach has consisted in the expansion of data sources and related techniques for exposure analysis, through the application of three main epistemic strategies.[3] At the macro level, exposome projects select data from longitudinal studies to use as a representation of the phenomena of interest – for instance the relation between air pollution and the development of cardiovascular disease in EXPOsOMICS (see e.g. Fiorito et al., 2018). On this basis, exposome researchers usually employ a microscopic strategy, whereby high-throughput methods are employed to generate high resolution data on exposure at an internal and external level. This is considered a way to collect evidence of exposure and disease at the specific level of individual participants to the aforementioned longitudinal cohort study, including for example molecular data to study possible reactions to pollutants and geographical data to estimate the presence of pollutants in the environment of the cohort (Vineis et al., 2017). As a third and typically final step, the data collected at the macro and micro level are statistically ordered and analysed to identify associations between elements and features of the environment and health outcomes. As a result, for instance researchers in EXPOsOMICS developed claims about the connections between specific types of exposure to chemicals and cardiovascular disease and the potential pathways and processes of disease development (Russo & Vineis, 2016).

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[2] Here I am mostly referring to environmental and infectious disease epidemiology, as the area of research that has evolved in relatively separate ways from clinical epidemiology and for instance diverged substantially in the context of the COVID-19 pandemic (Fuller, 2020).
[3] This identification of the epistemic strategies applied in exposome research is based on my analysis of the "data workflow" used in the EXPOsOMICS project (Canali, 2020b).

3. What is new about the exposome?

In which sense – if any – is thus research on the exposome a case of scientific change? In order to analyse the understand its impact on biomedical research as a case of scientific change, I start by distinguishing a few different aspects and meanings of the word exposome.[4] The exposome is discussed by epidemiologists and health researchers in these ways at least:

- As a new conceptualisation of exposure for epidemiology, at the theoretical level
- As the materials, methods, and techniques employed when studying the exposome, so as a specific approach to apply in research practice
- As the institutional, social, and funding context, where the exposome is studied and exposome research is maintained, hence referring to the exposome as a specific field and context of biomedical research[5]

Analysing the ways in which the exposome is discussed as a new concept, is studied through new methods, tools and techniques, and is applied as a new approach in institutions, communities, and funding streams shows that these three aspects have interacted in a way that makes it difficult to clearly separate them – to the point that the question of what comes first or is the main force of change is complicated and perhaps not central for philosophical models of scientific change.

3.1 The exposome from a conceptual point of view

The exposome is first of all a new notion – in more specific terms, the exposome is a new conceptualisation and an expansion of exposure (Vrijheid, 2014). Traditionally, epidemiologists have mostly discussed exposure in externalist terms, i.e. as the proximity or contact with an external entity that might transmit disease or affect outcomes of interest. The exposome notion expands this approach to exposure by distinguishing between different dimensions of external exposure (generic external exposure, including e.g. socio-

[4] I am grateful to an anonymous referee who pushed me to make this distinction, specify what these aspects refer to, and explain how they interact as part of my model of scientific change. My discussion here is also a way of following distinctions between material, social, and epistemic components, introduced by Rachel Ankeny and Sabina Leonelli in their work on repertoires (Ankeny & Leonelli, 2016).

[5] Here I am following the notion of "context" developed by Catherine Herfeld and Chiara Lisciandra, who use it to "indicate in a very general sense the circumstance in which knowledge is produced, transferred, and applied" (Herfeld & Lisciandra, 2019, p. 4).

economic status, urban/rural environment, climate; and specific external exposure, including e.g. radiation, infection, diet.), and introducing the notion of an internal dimension (including e.g. metabolism, inflammation, oxidative stress, etc.).

What is particularly interesting for discussions of change is the addition of an internal perspective on exposure: the notion of internal exposure is new for epidemiological research, but not for biomedical research more generally. Internal exposure has been used for decades, for instance in biomarkers and exposure science, where the notion refers to the measurement of the concentration of agents and chemicals that come from the external environment and are present in blood. Internal exposure has been transferred in the exposome context to characterise the presence of these external chemicals as well as processes that take place as a reaction to or in parallel with them. This means that, for example, internal exposure can refer to both molecules involved with endogenous processes, such as inflammation, and molecules more directly connected to environmental chemicals, such as $PM_{2.5}$. In the EXPOsOMICS project, exposome researchers produced exposure profiles to study internal exposure – lists of molecules that can be found in the samples withdrawn from the longitudinal study, which were used to understand their molecular composition and thus study the relations between external and internal dimensions of the exposome. In the case of EXPOsOMICS studies such as Fiorito and colleagues' work (Fiorito et al., 2018), the analysis of the internal dimension of exposure was conducted through an omics technique – proteomics – to search for proteins that may be related to inflammation. Omics techniques are employed to quantify and study types of molecules at various levels of an organism, for instance in the functioning of the metabolism, protein synthesis, DNA and bounding, etc.

The expansion of the concept of exposure as part of the exposome has thus particularly involved the internal dimension and has been the result of the transfer of conceptual resources from other areas of research, specifically biomarkers and exposure science. At the same time, however, the application of this conceptual expansion of exposure has been crucially connected to the use of omics techniques and data analytics, which in turn have been developed in other areas of biomedical research. Exposome research is one of the first areas where omics techniques have been transferred from genomics and aligned with the goals and methods of epidemiology. The use of internal exposure in the exposome has implied an expansion of the original notion as well, thus creating something new at both ends of the (disciplinary) spectrum: the concept is new to epidemiology, but its use to characterise endogenous processes is new with respect to biomarkers research and exposure science too (Canali, 2020a).

3.2 The exposome as an approach

An analysis of the conceptual changes of the exposome approach shows how the typology based on the three aforementioned axes works only to an extent, and the same is true if the analysis is focused on the exposome as a new approach for epidemiological methodology. One of the main changes at this level has been that the different dimensions of exposure are measured and studied simultaneously, as opposed to the traditional focus on single types of exposure. The goal of the approach in this sense is to identify connections between these different levels, in order to study disease as it develops through the different components and moves through pathways.

In this direction, in EXPOsOMICS data practices focused on both internal and external dimensions of exposure for each participant to the selected longitudinal study. On top of omics data, which were used as evidence of internal exposure, EXPOsOMICS include a team that transferred, developed, and aligned Geographical Information Systems (GIS) for epidemiological research and provided estimates of the environmental exposures that participants could have been encountered during the study period (Canali, 2020b). For instance, GIS can be used to compute pollution data collected by air quality monitoring stations and develop geo-spatial model assigning estimates of the presence of toxicants in different regions. In EXPOsOMICS, these models were used to estimate the presence of specific pollutants (e.g. $PM_{2.5}$) at the postcode level where participants lived during the cohort study period (Gulliver et al., 2018). The integration of these diverse sources of data in exposome research is conducted through statistical methods that look for potential associations between exposure at external and internal levels and the development of disease or other outcomes of interest. For example, one of the group of researchers working in EXPOsOMICS developed the Meet-In-The-Middle approach, a methodological approach that aims at identifying associations between air pollution and cardiovascular disease as well as the pathways through which cardiovascular disease could have developed (Chadeau-Hyam et al., 2011). This is a methodological innovation that can be interpreted as a step in the direction of more explicit and committed causal claims and thus promises to be significant for causal inference in epidemiology.[6]

These and other changes at the methodological level are again clearly connected to the changes brought by the exposome concept, most importantly the conceptualisation of internal exposure as one of the dimensions of the exposome, and at a material level, with the employment and use of omics and GIS data. More generally, these changes are crucially connected to the expansion of the material and evidential basis of epidemiological research, with the introduction of new sources of data. Omics techniques were originally developed in

[6] See Russo (2009) on traditional approaches to causal claims in epidemiology and Russo and Vineis (2016) and Canali (2019) for a critical reflection on the promise of exposome research to change this landscape.

the context of genome-sequencing and mapping projects at the start of the century and are now used in various areas of the life and health sciences (Hilgartner, 2017). Omics are high-throughput techniques, which can produce and collect large volumes of diverse data in relatively short turnouts. In this sense, the transfer of omics techniques and data has been crucial for the development and application of the exposome approach, enabling the study of the internal component of the exposome and the integration of data about all the three levels of exposure. Again, the exposome approach has brought about change at the methodological level of epidemiology, raising to become a specific approach and way of doing epidemiological research – but this change is clearly connected to changes at other levels and transfers from other areas of biomedical research.

3.3 The social and institutional context of the exposome

A final aspect of the changes related to the emergence of the exposome as a conceptual and methodological framework in epidemiology is the establishment of funding streams, data infrastructures, disciplinary pathways, and laboratories, which amount to a new area of epidemiological and biomedical research.

After its initial introduction, the exposome has had an increasing presence in scientific publications and projects, at least since 2010 (Siroux et al., 2016). In Europe, projects on the exposome have been successful at creating influence and securing short-term funding from the European Commission. The latest funding programme of the EU Commission – Horizon 2020 – had a dedicated track for the exposome, which directly funded projects including EXPOsOMICS and defined the exposome a "toolbox for assessing and addressing the impact of environment on health".[7] This has created lines of work in exposome research that have reacted more or less directly to policy requests and needs, such as ongoing revisions and updated to exposure assessment for air pollution and water contamination. In other parts of the world, the influence of the exposome has led to research centres being established to focus precisely on the exposome. For instance, the Exposome Collaborative at Johns Hopkins University was funded in January 2019 to "congregate the intellectual and material resources housed under the various disciplines within environmental health sciences and

[7] See https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/sc1-bhc-28-2019 (accessed May 2022). The same core team of researchers that worked in EXPOsOMICS has been particularly successful at securing funding from the EU in the last decade and is continuing to do so and thus shape exposome research in the European context. See for instance the more recent Lifepath consortium, discussed by Virginia Ghiara and Federica Russo (2019).

engineering and to evaluate the exposome in a holistic manner”.[8] Another significant element of innovation at this level is the disciplinary composition of researchers working on the exposome, which is diverse and comprises backgrounds ranging from molecular biology to medical science, from statistics to geography. EXPOsOMICS is again useful to exemplify this feature: the consortium included centres and researchers working in wearable technology, information systems, biology, epidemiology, genomics, etc. The study of the exposome in epidemiology is thus bringing new types of expertise and backgrounds into epidemiology, further diversifying types and styles of work in epidemiology (Morabia, 2004).

As such, research on the exposome has been a novelty for epidemiological research. In particular, the framing of the exposome as a complement to the genome has been a crucial rhetorical tool to influence and access solutions and infrastructures developed in the genomic context and funding streams normally dedicated to genomic projects. Again, research on the exposome has created innovation at the institutional, social, and funding level in connection to changes at other levels, transferring and adapting them from other lines of research.

4 Philosophical models of change, and some limitations

I have framed research on the exposome as a novelty from conceptual, material, and social viewpoints – but how should we model it philosophically as a case of scientific change? Reviewing some of the most influential views on change expressed in philosophy and the sciences, I argue that we need to expand our approach to scientific change. My intention here is not to discuss all the contributions on the philosophy of scientific change that have been developed in the literature, nor to reject available models tout court – I want to provide a short overview of the range of available accounts of change and discuss how and why we need to complement them. Most existing models of change do provide resources to analyse and explain the change we see in the case of exposome research, but have limitations when it comes to processes that are increasingly present in contemporary science and in the biomedical context in particular.

4.1 Change and continuity

Arguably, the starting point of philosophical discussions of scientific change has been to interpret change in continuous terms. Several philosophers have developed continuous and linear models of change, which have for instance been used by logical positivists and

[8] See https://publichealth.jhu.edu/departments/environmental-health-and-engineering/research-and-practice/faculty-research-interests/the-exposome-collaborative-johns-hopkins-university (accessed May 2022).

empiricists to highlight the cumulative nature of scientific change. In this context, change is a phenomenon capable of building on established concepts, theories, and explanations in order to pave the way for scientific, political and social progress (Creath, 2021; Nickles, 2017). Part of the problem in applying this work to contemporary science is the focus on the role of theories and theoretical components of scientific epistemology.[9] In cases such as the exposome approach, we have seen that conceptual changes are indeed crucial, but they are clearly connected to changes at the technical, methodological, and material level – for instance, a conceptual novelty such as internal exposure is crucially linked to the interpretation of omics data as evidence of the internal dimension of the exposome. In this sense, while the exposome approach is in significant continuity with longstanding approaches in epidemiology, this seems significantly different from the focus on conceptual continuity discussed in these accounts. Contemporary discussions on scientific change have reached similar conclusions, as for instance Sabina Leonelli and Rachel Ankeny have argued that the (exclusive) focus on cases and examples of conceptual and theoretical change side-lines other significant types of scientific change, especially in contemporary science (Ankeny & Leonelli, 2016).

Other and more recent work along these lines, such as the evolutionary accounts of change developed by Larry Laudan, Dudley Shapere, Philip Kitcher, and Nancy Nersessian, do more and go in a slightly different direction. For example, Nersessian has developed a model-based account of reasoning that is grounded in the analysis of several, concrete cases of change in contemporary science (see e.g. Magnani et al., 1999). In addition, these accounts emphasise the importance of continuity through change and do so by specifying how conceptual change is often connected to social and material factors. For instance, Kitcher has argued that the development of scientific concepts and theories is deeply affected by the features and dimensions of specific social, historical, cultural contexts (Kitcher, 1995). This is a crucial starting point of my work in the article, as we have seen in the previous section and as I will detail in presenting transfer as one of the processed modelled by the pragmatic approach. However, the general framing of continuity is still limited in this context: most work in this line of research is focused on historical analyses and, as a result, continuity that these accounts discuss is primarily historical. In cases such as the exposome approach, change is not in continuity with the historical approaches of one field or area of research but still shares significant continuity with other areas or disciplines. For example, the change established through the study of the exposome is largely a continuation with some existing approaches in other areas of the health sciences, which has enabled a project such as EXPOsOMICS to work as a consortium of interdisciplinary teams from epidemiology

[9] Even in cases of early discussions on the relation between different areas of research, the focus is very much on theories – for instance interfield theories as the powering force for change and integration between fields (Darden & Maull, 1977).

and biomedical sciences, as well as information science, geography, social sciences, etc. The same is instead not true with respect to contemporary epidemiology, with which the exposome is only partially in continuity (Canali, 2020a). This highlights a situation where continuity seems to be more horizontal than vertical from a historical point of view, and thus the processes of change and continuity that instantiate and propagate change are different. Change is not just about establishing a new area of research or approach with respect to the history of a field, but with the different histories, communities, practices that are present and connected in other fields.[10]

4.2 Scientific change and revolutions

One of the most influential models of scientific change for philosophy and beyond is of course based on the work of Thomas Kuhn, who focused on dramatic changes that produce a strong discontinuity with the previous ways of conducting research and are the result of a period of crisis, as the old paradigm ceases to deliver the intended results and significant anomalies are identified (Kuhn, 1962). This is perhaps the most important instance of revolutionary models of change, which have been crucial in making scientific change a classical topic of philosophy of science and in framing approaches to change in philosophy, the sciences, and beyond (Nickles, 2017). In more recent work in this line of research, Paul Thagard has worked on scientific revolutions and their impact on conceptual frameworks and taxonomies (Thagard, 1993). This focus on the conceptual consequences of scientific revolutions has been significantly extended by philosophers in collaboration with psychologists and cognitive scientists (Nickles, 2003). Brad Wray has worked for instance on the theoretical nature of scientific change in revolutions, which can involve whole scientific communities and yet often requires time to expand and become substantial (Wray, 2011). The idea of revolutions and paradigms is also very popular in the sciences (Hoyningen-Huene, 1993): the exposome itself has been discussed as a new paradigm for epidemiology (Miller, 2020).

Many features of this way of modelling change are crucial to understand the case of the exposome approach. Consider Kuhn's seminal work framing scientific change as the intersection of conceptual, social, and material factors – in the previous section, we have seen these factors intertwining concretely in the context of research on the exposome. Revolutionary models of change have also clearly discussed scientific change as a phenomenon that needs to be structured and implemented beyond conceptual and methodological aspects, for instance at the social and infrastructural level in science

[10] This horizontal viewpoint is indeed present in other contemporary discussions on scientific change in philosophy of science, including work on alignment that I discuss below (Ankeny & Leonelli, 2016; Leonelli & Ankeny, 2015).

education, funding, etc. – I will use this as a starting point for my discussion of influence as a process of change modelled by the pragmatic approach. However, the case of the exposome seems to differ considerably from revolutionary models. Several elements that have led to the exposome as a concept, approach, area of research have been transferred from elsewhere – as a notion, the exposome lies in continuity with these areas and has increased the plurality of approaches available in contemporary biomedicine, instead of creating disruption and incommensurability. For instance, the notion of internal exposure has been developed in biomarkers and exposure science, where it has been used for years as a way of characterising the concentration of environmental chemicals in tissues (Russo, 2016). Its transfer into epidemiology with the exposome has enabled the expansion of the notion of exposure and the interpretation of omics data as evidence for the study of exposure. In turn, the adaptation of this notion in epidemiology has also implied a shift and further expansion of the original notion, which in the context of exposome research refers to both intermediate metabolism and endogenous processes. In other words, this transfer has led to various changes – it has brought conceptual, methodological, and technical tools that are new for epidemiology, as well as new variations, interpretations, and uses of a concept originally developed elsewhere. Work in revolutionary models of change is a useful resource for thinking about change in the case of the exposome, but the centrality of transfer in exposome research seems distant from revolutionary change. The conceptualisation of exposure based on the exposome framework has not really been a sudden and new world view for biomedical research and has indeed been transferred from other work in the biomarkers and exposure science and aligned within the epidemiological context. In addition, the result of this and other instances of alignment in the exposome approach is not incommensurable with other approaches in epidemiology and beyond, at least not in the strong sense that seems to be the result of scientific revolutions.

4.3 Technology, data, scientific change

A third line of work that I want to mention in this overview is focused on the role of technology in scientific change. Considering the importance of data and related analytic technologies in the exposome approach, for instance omics and GIS data and techniques in EXPOsOMICS, it could be argued that the most important driving force of change in this case is the technology to collect and analyse data. This would align well with ideas of big data as a scientific revolution – the idea that the growing volume of data produced, stored, and used for various purposes can create revolutionary change at various levels, including in the sciences (Kitchin, 2014). The amount of data scientists can collect, analyse, and use has indeed increased significantly in the last decades (Strasser, 2019) and the introduction of data including omics and GIS through the exposome has significantly expanded the evidential basis of epidemiology (Fleming et al., 2017). Yet models of change that emphasise the role of data and related technologies in revolutionary terms are not particularly helpful to characterise change in the context of exposome research, as they largely neglect the need to approach data with other components of scientific epistemology. Many of the innovations of the exposome approach are clearly connected to and shaped by the availability and use of new data – yet conceptual and theoretical considerations are very much at the centre of exposome research, and these new, diverse, and large sources of data are connected to the employment and development of new concepts. For example, the availability of omics data has made it possible to study exposure at a microscopic and internal level, thus allowing for the conceptual expansion of exposure to internal dimensions, but the use of notions from biomarkers and exposure science has been crucial here (Rappaport & Smith, 2010).

These considerations on the role of data in the exposome approach go in the same direction as crucial work of philosophers and science scholars, which has closely analysed claims of scientific revolutions fuelled by big data and has downplayed the revolutionary power of data-intensive methods (boyd & Crawford, 2012; Iliadis & Russo, 2016; Leonelli, 2014; Ratti, 2015). This critical work has been key for the development of a philosophical focus on data and is a crucial starting point for my work on data and alignment in this article, as I discuss in the next section. Yet, this line of research has only partially engaged with background views of change by data and technology and has not provided alternative models of change in this direction. At the same time, other discussions on the role of technology in science have been developed by science scholars, philosophers, and historians of science and technology. These analyses offer powerful tools to understand the role of technology and its results and products, such as data, in the exposome approach. Data have indeed shaped research to a significant extent: for instance, in the EXPOsOMICS project, the use of omics data has meant that more traditional sources of observational data had to be adapted and different sources of environmental data had to be identified – these are significant tasks, which include sometimes controversial aboiut which types of data and evidence to use. Similarly to this case, Peter Keating and Alberto Cambrosio's work on "the institutional and epistemic hybrid we call biomedicine" (Keating & Cambrosio, 2003, p. 368) places key importance on technology and laboratory techniques as a distinctive feature of the biomedical perspective (Valles, 2020). Hans-Jörg Rheinberger has shown the centrality of experimental systems and data practices in the historical development of biology, where technological considerations often trump theoretical frameworks (Rheinberger, 1997). Yet, most of the focus of this line of research has been on the impact of technology on scientific methodology and epistemology, rather than scientific change. This is not a problem for these accounts per se, but they can help only to an extent when discussing the role of data and related techniques in scientific change. In addition, in the EXPOsOMICS project the use of omics data has opened new areas of research, but this effect has not been automatic or immediate – it has placed significant constraints and requirements for alignment, as I discuss in the next section.[11]

5 Towards a pragmatic approach to scientific change

Instances of change such as the exposome approach call for an expansion of the philosophy of scientific change, with the goal of making sense of new cases of change and complementing available models. In the previous section, I have mentioned other and more recent developments in the philosophy of scientific change: many of these are indeed ways to expand philosophical approaches to change, and not just rebuttals of traditional perspectives (Soler et al., 2017). In particular, I argue that three main methodological features are shared across new discussions of scientific change and have significant consequences for the way we should approach change: the focus on contemporary cases of change; the attention to the small-scale at which change can happen; and the expansion of the units of change beyond theoretical and conceptual components (Ankeny & Leonelli, 2016; Gross et al., 2019; Herfeld & Lisciandra, 2019; Shan, 2019). Together with the more traditional work discussed in the previous section, these contributions constitute the main starting point of my work. What I think is lacking in this line of work is the development of specific approaches to change, at least in a similar sense to which the revolutionary and linear approaches are models of change. The development of models of change is significant philosophically and beyond: models can give us a specific picture and understanding of change, make assumptions explicit, and signal phenomena and aspects that can instantiate change in contemporary science. Furthermore, several different approaches can be developed on the basis of recent work on scientific change, so it is crucial to clarify *which* approach needs to be applied to specific cases of change. Approaches and models are also useful to detail the specific processes though which change happens – something that various work in current philosophy of science does, but with little discussion of the interrelations between these processes and the overall picture of change that is their product. Following these considerations, my contribution to the debate is a *pragmatic* approach, which puts the emphasis on processes of *transfer*, *alignment*, and *influence*; and identifies, in pragmatic terms, types of processes that may differ substantially depending on the specific circumstances. For example, the type of transfer at the basis of the exposome approach is very much specific to the recent and current state of epidemiology and would not necessarily translate to other contexts. The ways in which influence is exerted in

[11] For instance, the combination between large volumes of data and short-term funding has created problems for the analysis of all the collected data in the case of EXPOsOMICS, an issue that is typical of many data-intensive projects in biomedical research (see e.g. Leonelli, 2013a).

biomedical research is also very different from other contexts, where for instance broad narratives of benefits that are typical of health-related research are not present.

5.1 Transfer: initiating change

A first process of change that the pragmatic approach identifies is transfer – the process that generates and starts change. Transfer can concern conceptual elements such as specific understandings, notions, theories, as well material, methodological, social, and technological components. Transferring usually happens from one area of research, project, or discipline to another. The transferred elements can kick-start change as novelties for the area where they are introduced, but their adaptation to the new context of use can also lead to changes and updates to the elements themselves. Transfer creates change with usually strong continuity between areas of transfer – this continuity, however, is mostly at a horizontal, rather than vertical level: continuity with respect to other areas of research, rather than previous or existing work in the same field.

As such, transfer can take different forms depending on which components are transferred and which consequences transfer has – in this sense, transfer can be conceptual, methodological, technological, organisational. In many cases, transfer that elicits scientific change is knowledge transfer, which can include theories, models, evidence (Herfeld & Lisciandra, 2019). Yet transfer in the sciences is increasingly present at other levels. In the biomedical sciences, consider the case of the Human Genome Project and its significance as a cluster of new methodological tools and organisational schemes that have been transferred to so many other areas of research. The philosophical, sociological, historical literature on the Human Genome Project has shown crucial features of transfer as a process of change: not all components of the Human Genome Project have been successfully transferred to new areas of research and transfer has elicited change by presenting novelty to new fields, but also by substantially changing the original elements (Hilgartner, 2017). As a result, transferring a conceptual component can clearly lead to conceptual changes, but also methodological and organisational changes: as such, transfer can create different requirements for what needs to be aligned and how and is thus crucially tied to the second process of change that I discuss below. This is one of the reasons why I present my approach as pragmatic: we need to be open to model different types of components that may be transferred and different processes that results from transfer and are related to alignment. Depending on the specific case of scientific change that we want to analyse, some types of transfer and change might be more relevant to focus on than others.

In the case of exposome research, transfer has mostly worked at conceptual and methodological levels. As we have seen, the notion of internal exposure has been transferred from biomarkers and exposure science, as a way of framing the internal dimension of the exposome and conceptualising molecular reactions to the environment as kinds of exposure. Moreover, so much of the exposome as an approach can be considered an extension of omics technologies and data into epidemiology – in this sense, the EXPOsOMICS project included specific teams with an expertise on molecular biology, sequencing, and genomics to apply omics techniques to exposure profiles. The transfer of these elements has created changes in the conceptual dimension and practical application of the exposome approach in epidemiology, but also kick-started reflections at the methodological level, leading for instance to the development of the Meet-In-The-Middle approach (Chadeau-Hyam et al., 2011).

At the same time, the case of transfer in exposome research has not included only literal applications of available material: it has led to original modifications and new uses. For example, the way in which internal exposure has been conceptualised and applied in projects such as EXPOsOMICS is a partial step beyond the use of the concept in biomarkers and exposure science – it is not just a way of conceptualising the concentration of external agents in blood, but also processes in reaction to those agents, such as inflammation. Similarly, omics techniques were originally developed in the context of sequencing and genomic projects and their application for exposure profiles has led to the development of specific techniques for this new use. For example, EXPOsOMICS was one of the first groups to invest in the development and application of adductomics, an omics technique that measures the binding of proteins to specific toxicants and was used to study the long-term effects of exposure on protein development. As such, transfer has created change and innovation both for epidemiology and the original areas from which the elements were moved from – to the point that the exposome approach shows little epistemic dominance within epidemiology and significant continuity with respect to areas including biomarkers science and genomics. A plurality of approaches to the issue of disease aetiology and analysis are indeed present in the current landscape of epidemiological research, which have not necessarily been replaced by the exposome approach (Broadbent, 2021; Vandenbroucke et al., 2016); and pluralistic conceptualisations and approaches to what counts as environment exist in various areas of the health sciences (Canali & Leonelli, 2022).

Processes of transfer and continuity place the pragmatic approach relatively far from revolutionary accounts, which identify precisely in the disruption and absence of continuity brought by revolutions the mark of scientific change. The change brought by processes of transfer is in this sense closer to ideas of pluralisation discussed in recent work by Fridolin Gross, Nina Kranke, and Robert Meunier (Gross et al., 2019). Transfer is also one of the processes that can lead to the establishment of the research repertoires discussed by Ankeny and Leonelli, and the exposome approach can in a way be seen as one of the available research repertoires of current epidemiology (Leonelli & Ankeny, 2015). In the context of exposome projects such as EXPOsOMICS, continuity has been crucial to establish collaborations, integrate discourses and narratives from other areas of research, and present innovation in their connection: some of the rhetoric of the exposome approach is inspired by the genome and its success at securing funding, with the presentation of the exposome as both a complement to the genome and a way of filling in the gaps of genomic research, especially when it comes to disease aetiology (Rappaport & Smith, 2010). The continuity identified by the pragmatic approach exists horizontally here, between different areas of research and fields rather than historically within a specific area of research.

Continuity shows two additional and crucial features of transfer as one of the processes modelled by the pragmatic approach. Facilitators play a crucial role in processes of transfer and can make or break transfer, by translating components between different areas and promoting alignment, or making it easier to transfer components at the start point of research. The case of the exposome approach is particularly interesting in this sense. Epidemiology tends to lack strict criteria at the educational, methodological, and conceptual level and projects such as EXPOsOMICS usually include statisticians, medical doctors, biologists, computer scientists – several of these researchers can play the role of facilitators and have done so in EXPOsOMICS. However, the transfer of genomic approaches and omics data has also created barriers for further interdisciplinarity, as data collection techniques that are more traditional of epidemiology are significantly different in terms of volume, tractability, analytic techniques and the use of omics is arguably pushing in different directions. For instance, EXPOsOMICS researchers sometimes lamented the lack of interdisciplinary communication and understanding of the data practices involved in omics and GIS and the use of genomic approaches has sometimes been discussed as reductionistic. A second point that is important to stress and is interesting to see in the case of the exposome is the relation between transfer and time, as a feature of change. In most cases, transfer is the first chronological process that elicits the types of change modelled by pragmatic approaches, or at least is the first process that can signal change and show the need to focus more on a specific case. It is difficult to determine the starting point of processes of change in the context of the exposome, which was introduced at a specific point in time as a concept (Wild, 2005). This concept included internal exposure, which as we have seen has played an important role for connections with other communities and areas of research. At the same time, the methodological transfer of omics techniques into epidemiology was presented as a crucial starting point for change already at the introduction of the concept – it seems difficult to say that change started with either cases of transfer, but both processes signal the need to focus on this as a case of scientific change.

5.2 Alignment: establishing change

A second process of change highlighted by the pragmatic approach is alignment. Logically – and in most cases chronologically – this is the step that comes after transfer and concerns the integration of the transferred elements into the new context and the adaptation of other research components to the new arrival. Alignment is a re-configuration of available material that can affect methodological, conceptual, material, social, methodological elements of research. Successful alignment instantiates change as it shapes several aspects of research projects, including theories, strategies, funding, disciplinary backgrounds – to the point that alignment can create previously non-existent or significantly renovated areas of research.

The exposome approach showcases this process at several levels, for instance at the material and methodological level, in the case of omics techniques and data.[12] As we have seen, one of the innovations of the exposome approach has been the introduction of these data and related analytic techniques developed in the genomic context. This transfer, however, has not been responsible for change directly on its own: omics data have substantially different features from the traditional datasets used in epidemiology, at the level of abstraction, volume, material, format. As a result, in projects such as EXPOsOMICS, the need to align omics data with the latter and other sources has elicited the development of new epistemic strategies, which in turn has led to the use of additional and new data such as GIS data. The study of the exposome has in this sense been one of the main ways in which molecular approaches have been introduced into the epidemiology, with a move that has contrasted with the more traditional population thinking approach and focus of epidemiological methodology (Morabia, 2004). Alignment is also a contested aspect of the exposome approach, which has been criticised as an extension of the reductionism of genomic approaches and the molecularisation of social determinants of health and disease (Richardson & Stevens, 2015).

Thus, the types of elements transferred through the exposome approach (omics data) have created the need to align material and methodological components of epidemiology (data analysis, statistical approaches, etc.), resulting in a specific type of alignment and change (the exposome approach). But alignment can vary considerably in relation to the types of elements that are transferred and need to be aligned: just like transfer can be conceptual, methodological, technological, organisational, so alignment can focus on conceptual, methodological, technological, organisational components. The interrelations between transfer and alignment can be more complex still – transferring a conceptual component into a new area of research can clearly create the need for conceptual alignment, but methodological and organisational components might need to be aligned too. For instance, the transfer of omics data in the case of the exposome approach has created the need for

[12] Here I am approaching data as material and epistemic artefacts, which result from the processing of the material interactions between the world and the objects of scientific investigation. This does not mean that data are fixed, mind- and theory-independent representations of those interactions, nor that the material features of data fully determine its evidential value. For a discussion of materiality and data see Halfmann (2020).

alignment with other data and the collection of new data. But alignment has also been necessary beyond this level, for example with the development of new statistical approaches and epistemic strategies, or at the organisational level with the establishment of collaborations for data collection and analysis for both omics and GIS data. This is the point where we also see the possible limitations of alignment in the context of the exposome. As we have seen, the employment of omics and GIS techniques and data has been at the basis of the raise of molecular and microscopic approaches to the study of exposure and disease. The extent to which these approaches can be aligned with existing methodologies in epidemiology, however, is the object of ongoing discussions in the field and the exposome has only partially settled these issues. Success at alignment is and will be crucial for the future history of exposome research as a case of change: as a process of change, alignment is thus another point where change can both be elicited and hindered.

These considerations render alignment as a process that can take many forms and – much like transfer – shows the need for a pragmatic interpretation of the processes that can elicit change and vary substantially in concrete cases. Focusing on single components, for instance theories or technology, can help specify analyses of scientific change, but also lead incomplete pictures of change. For instance, omics data have clearly played a crucial role for the innovations of exposome research and methodology, but their use was only possible thanks to additional changes and their alignment with new and existing approaches – to the point that focusing on data only gives us an incomplete picture of the processes of change in case of the exposome approach. This is the point where technological narratives often fail in modelling scientific change: for instance, views of big data as scientific revolutions have often framed data as automatic sources of change for scientific epistemology, but cases such as omics data clearly show a more complex picture – data are often and perhaps increasingly sources of change, but change is mediated by alignment and thus involves other components too.[13]

Alignment is a crucial point of discussion in science studies, for instance in the context of work resulting from "practice turn" (Bschir et al., 2019; Soler et al., 2017). In philosophy of science, the analysis of processes of alignment for scientific change is relatively recent and has often been the result of going beyond theory-centred models of change and focusing on other components as forces of change, for instance in work on collaborative research (Ankeny & Leonelli, 2020). The focus on alignment as part of the pragmatic approach is also connected to the concept of integration, which has been substantially discussed by philosophers, especially philosophers of biology (Brigandt, 2010). Integration practices are a

[13] See several cases where data have elicited change in the volume edited by Sabina Leonelli and Niccolò Tempini (2020), which shows the substantial and complex work that is needed to make sure that data can "travel" and transfer into new areas of research.

way in which alignment can be achieved and can be used as a focus for a discussion of the ways in which conceptual, material, and methodological components are aligned (Leonelli, 2013b). For example, in crucial work in the philosophy of scientific data, the concept of data journeys has been used to discuss the practices that 'prepare' data for transfer to new areas of research, which shows the need for these practices and counter simplistic views of data as immediate representations of reality (Leonelli, 2016, Chapters1-2). The pragmatic approach shows that this type of data practices has a significant effect on the ways in which and the extent to which data can be aligned and thus create change. Choices at the level of data journeys have consequences on the feasibility of data integration as well as the possibilities and forms of scientific change. These considerations on alignment and data journeys indicate a crucial role for data curators and stewards as facilitators of alignment and change – if data are curated and presented in ways that enable journeys and transfers, there will also be clear indications for the types of alignment needed. The case of exposome research shows these relations between alignment and data practices and journeys in several ways. For instance, the relatively open disciplinary barriers of epidemiology have enabled epidemiologists in exposome projects to play the role of coordinators between difference disciplines and thus facilitators of processes of alignment. This does not mean that alignment has been an automatic process, however, nor that it is an aspect of change that takes place only at the chronological start of histories of change. Alignment processes are clearly reactions to processes of transfer and thus are often a second chronological step in cases of change, but for example the need to integrate and align omics data with existing and new methodologies in exposome research frames alignment as an ongoing process that requires constant attention – especially in connection to the further establishment and expansion of change in a data-intensive context.

5.3 Influence: extending and expanding change

A final process that the pragmatic approach to change underlines and is a result of transfer and alignment is what I call influence – the epistemic, material, and social power that can come as a consequence of change. This is a process that can be considered the endpoint of change discussed by the model, in a dynamic sense potentially leading to further updates and changes. Influence is directly tied to both transfer and alignment. Transferring established components can create situations where innovations can also exert their influence on other and new spaces, for instance by aligning them to the methods, concepts, materials transferred from another area of research. In turn, without alignment influence can hardly have an impact in a new context. Processes of alignment, as we have seen, can include the establishment of collaborations between different fields, thus potentially also enabling bridges between disciplines where a case of scientific change can extend its influence on a new field. In addition, the innovations elicited by transfer and established through alignment can extend the influence of concepts, methods, materials into new areas of the same field – as we see in part in the case of the exposome.

Influence is also a process that looks beyond the processes of change discussed so far and is tied with other processes involved in future changes. In this sense, influence can be seen as chronologically happening at the end or the start of histories of scientific change, but also throughout a specific history of change. For instance, the new methodological tools and data of omics techniques have been an initiator of change in many areas of research in the life sciences, to the point that some have argued that they have contributed to establish a post-genomic era in biomedical research (Richardson & Stevens, 2015). The case of the exposome approach can thus be seen as instance of influence from genomics into new disciplines, in this case epidemiology. However, the case of exposome research also shows an active role for influence – the exposome has been presented as an umbrella concept that can be applied to other disciplines in the health sciences, including for instance exposure science, but also other areas of research within epidemiology, such as areas of research beyond environmental epidemiology.[14] There is also another time component where we can see influence in action, as in some cases of change influence can take place at an early stage, as a way to start transfer and alignment. The initial introduction of the concept of the exposome by Wild (2005) was clearly directed at epidemiology, but not only, and the introduction of the exposome as a new concept capable of influencing other fields can be seen as way of legitimating the need to change and introduce a new approach through transfer and alignment.

The history of the exposome in this sense is only partially written, and not only as a consequence of its recent history – the influence of the exposome notion and approach is still uncertain and unsettled. While the exposome approach clearly benefits from dedicated funding streams, individual centres, and research consortia, as we have seen, there are significant limitations to the influence of the exposome approach in the current landscape of biomedical research and epidemiology in particular. For example, EXPOsOMICS researchers lamented the lack of 'blue-skies' funding that is dedicated to genomic and sequencing projects. Exposome projects are mostly funded on a short-term basis. This is turn problematic because often there is not enough time to analyse and process the large datasets collected through omics and GIS techniques, long-term collaborations are more difficult to establish, and there is a constant need to pitch and propose new research ideas and topics. In turn, typically epidemiological research takes a very long time and needs longitudinal studies that look at the slow development and effects of exposure. The main way in which exposome research groups have tried to approach these issues is through the

[14] See for instance the application of the exposome approach to the epidemiology of early life (Robinson & Vrijheid, 2015).

establishment of research consortia, whose composition is often partially retained though different projects, such as in the case of EXPOsOMICS. Through the pragmatic approach we can model these struggles for funding as elements of influence, in particular as tests for the establishment of an approach within a larger field. The establishment of funding streams dedicated to the exposome approach within the larger field of epidemiology has enabled additional transfer and alignment of the approach, but in addition it has also created cases where approaches from other fields beyond epidemiology try and pitch their research as a response to these funding calls and thus aligning with the conceptual, methodological, material framework of the exposome.

At the same time, while work on the exposome is increasingly present in the biomedical literature (Siroux et al., 2016), the extent to which the notion of the exposome has complemented the genome and moved research beyond the genomic focus remains unclear. As we have seen, the study of the exposome is largely based on the transfer of genomic technologies and as such it has been criticised because of possibly similar reductionist conclusions (Shostak & Moinester, 2015). Nevertheless, the postgenomic context is increasingly varied and diverse and the study of exposome sits at the intersection of various trends in this sense, including the push to focus more on the environment, the expansion of the notion of exposure, and the study of climatic and environmental data in biomedicine (Leonelli & Tempini, 2021). Data play an interesting role in the context of these considerations. Scientific data are increasingly assets for political, economic, as well as epistemic interests (Leonelli, 2019b): in this sense, data can also play an important role to extend the influence of a case of scientific change. Consider for example the establishment of dedicated databases where a specific approach is systematically applied for data collection, interpretation, and use: in several cases in the life sciences, historically the establishment of a new approach to the study of biological phenomena has been tied to the collection of data and the raise of community databases (see e.g. the case of model organisms: Ankeny & Leonelli, 2011; Lohse, 2021). In this sense, the lack of funding dedicated to data practices is increasingly an obstacle to change, and the availability of large datasets that are already available can actually inhibit innovation and the collection of new data (Leonelli, 2019a).

This is one of the areas where the pragmatic approach brings in lessons from revolutionary models of change. From a Kuhnian point of view, new paradigms exert influence over specific areas of research, if not entire disciplines, with the methodological success of solving some new problems, the social abilities connected to establishing teaching and training programmes, the epistemic appeal of new frameworks and world views (Kuhn, 1962, chapter X). Similarly, the pragmatic approach identifies influence as a crucial aspect to maintain, promote, and establish change, but the type and means of influence of the pragmatic approach can vary substantially. The connection with transfer and alignment renders a type of influence that is less dominant and more local to specific disciplines. In addition, this influence of new and changing concepts such as the exposome is exerted through collaborations and alliances, rather than disruption and revolutions. For example, the group responsible for EXPOsOMICS has been successful in expanding its influence by establishing various collaborations, especially beyond epidemiology, with genomics, the social sciences, geography, information science (Illari & Russo, 2016; Russo & Vineis, 2016).[15]

6 Conclusion

How should we frame and conceptualise scientific change? In this article, I have argued that we need to complement philosophical models of change with a pragmatic approach, on the basis of recent work in the philosophy of scientific change and the analysis of the exposome approach in epidemiology. The exposome approach is a case of change for epidemiology – and yet, it is not a case of clear disruptive change, linear continuity, or technological innovation only. In particular, the exposome approach instantiates a type of scientific change where we see an important role played by material and methodological elements, the transfer, merging and adaptation of tools from elsewhere is crucial, and change does not result in the substitution of existing approaches with new ones, but rather an increase in plurality.

I have presented the pragmatic approach as a way of modelling transfer, alignment, and influence as key processes of change in contemporary science. As such, the pragmatic approach can enable 'situated' accounts of change, with reference to results from feminist epistemology and philosophy of science, whereby philosophers have argued for the need to locate accounts of scientific knowledge in their 'situation', i.e. locate epistemic practices, agents and knowledge in the material, institutional, and cultural context of their standpoint (Wylie, 2012; Leonelli, 2016, p. 190). The focus on situations allows us to identify scientific change that happens in local contexts, which would be difficult to detect otherwise, and is especially useful for the analysis of the role of material components such as data, whose impact often depends on specific uses and applications. The approach also allows for a more precise critical position from which to contribute on potential issues and challenges of scientific change. In this sense, moving forward in philosophical analyses of scientific change, I think it is important to emphasise the ways in which philosophy of science can critically approach and contribute to scientific change. There is a critical dimension to the assumptions and choices of the units of philosophical analysis of change: identifying the

[15] As an anonymous referee suggested, this discussion has important connections with work on progress in the philosophy of change and beyond. I will not discuss progress in this article, but the connections between change and progress in the pragmatic approach merit more work, for instance in the direction of disambiguating innovation, change, and progress.

units of change is one of the persistent problems of the debate and the pragmatic approach suggest a way of identifying the relevant units depending on the basis of specific areas of research (Gross et al., 2019, pp. 6–7).

Where does this leave us on the topic of scientific change more broadly? My analysis is limited to a specific area of the sciences and has focused on a specific case of scientific change. But the case of the exposome is an example of broader trends and phenomena of contemporary biomedicine, such as data-intensive approaches and postgenomics. In addition, some of the processes of change identified and modelled by the pragmatic approach seem to be common in science. For example, transfer is a common element of historical cases scientific change, as discussed by several historians and philosophers of science (Herfeld & Lisciandra, 2019; Chang, 2021). At the same time, processes such as alignment seem to be common in cases of interdisciplinary collaborations and the increasingly central role of material and technological components in alignment seem to be common in cases of data-intensive science (Ankeny & Leonelli, 2016). In this sense, the expansion of the units of analysis of scientific change in the context of the pragmatic approach shows the need for philosophical models to be reactive to scientific change. Scientific change in itself might change, as theoretical and conceptual shifts might not be the primary means through which change manifests itself – changes to the units of philosophical analyses can and sometimes should reflect changes in the ways in which change itself happens in the sciences.

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