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Article:
Emmel, N orcid.org/0000-0002-2154-5814 (2021) Post-disciplinary realism. International Journal of Social Research Methodology, 24 (1). pp. 95-108. ISSN 1364-5579

https://doi.org/10.1080/13645579.2020.1803526

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Post-disciplinary Realism

Nick Emmel

Abstract

In this paper I elaborate a realist post-disciplinary methodology. Its starting point are disciplines. Some features of disciplines are well understood. But the implications of their irreducibility to mechanical procedure is rarely acknowledged. Building on this observation this paper proceeds through investigating transdisciplinary methodologies. First science as usual in which disciplines are the building blocks of interdisciplinary science, additive in producing new approaches to the investigation of increasingly complex and broader issues. And then a pragmatic methodology in which knowledge is revised at the interface between the scientific community and a multitude of social actors with their competing demands and criteria of assessment. This investigation offers contrast that allows for the distinctive features of a post-disciplinary realist methodology to be identified; a narrative arc of inference to be described; and a call for a far more expansive and coherent post-disciplinary science.

Introduction

A pre-requisite of a realist methodology must be that it moves beyond the limits of institutionalised disciplinary science. Broadly, the object of its enquiry is characterised by dynamism and complexity (Byrne and Callaghan, 2013). This requires a methodology able to traverse the physical, natural and social sciences. If these were the only methodological challenges of realism then the solution might lie in interdisciplinary approaches that describe and interpret events. However, these are also open systems that resist closure. Realists also acknowledge a stratified (or depth) ontology. As this paper will elaborate, realist research intends to lay claim to the mechanisms that shape empirical events. Invariably, only these events are recordable through the empirical instruments available to us. Realism’s purpose is explanation, however tentatively, of generative causal mechanisms.

The aim of this paper is to work out a methodology to explain these complex events and their causal powers. Sayer (2000) and Byrne and Callaghan (2013) offer some of this methodological account, choosing to describe the changed relationships necessary for realist science as post-disciplinary.

Starting with familiar and well-rehearsed understanding of disciplines as laying claim to a domain of knowledge through their social and institutional structures, this paper argues they cannot be reduced to instrumental practices, the application of methods and technologies. There are practices within disciplines, sometimes called theorising, that are inherently realist. Although many scientists might not recognise this activity as such!

The paper then proceeds through an investigation of two accounts of transdisciplinary science, neither of which are realist. There is a literature that discusses this transdiciplinary science as post-disciplinary (Jessop, 2001, Stone, 2011, Sayer, 2000, Coles et al., 2005), but it is at present relatively limited. A far richer seam of methodological literature investigates approaches to transdisciplinary research to elaborate the key methodological debates considered here. This literature locates around two epistemologies. First, science as usual, arising from the disciplines and funding bodies of disciplinary science. This is characterised as the synthesis of method and language. It remains firmly anchored in existing disciplinary relationships and institutions, albeit occupying new moorings within these. The second case investigates a pragmatic account of transdisciplinary science intent on widening participation in a liberal democracy, responding to demands on science to make it socially relevant and introducing new criteria for the assessment of its value. This pragmatic account argues scientific knowledge cannot be reduced to advances in technique, method, language, the defending of boundaries between disciplines and the creation of new ones suggested in the science as usual account of transdisciplinary science. Instead, there is recognition of the need for an ongoing and decisive interpretation of knowledge that includes a multitude of social actors beyond the scientific community.

These approaches are found wanting, but together provide an arc from the descriptive power of disciplinary science and science as usual, through the interpretative inference of pragmatic science to the explanation of a realist methodology. A post-disciplinary realist methodology is characterised by a flattening of hierarchies of evidence, disputation within and beyond disciplines, experiment as argument and the breaking down of disciplinary walls to explain the causal generative mechanism that shape the empirical events described in disciplinary science.

Disciplinary science

That disciplines discipline their disciples is well established (Friman, 2010). Disciplinary scientists engage in a lengthy apprenticeship and training (or studentship) in which they learn and then practice methods and technical practice. They adopt exempla from a body of research specific to their discipline. These empirical accounts are brought into engagement with concepts that in turn provide a legitimate and epistemologically coherent body of theory specific to the discipline. This training is reinforced through teaching and a community bound together through a common jargon-heavy learnt language, journals, colloquia, conferences and deference to a hierarchy of expertise and insight into the discipline.

Disciplinarians guard fiercely the boundaries of their disciplines, patrolling the physical and intellectual spaces of their discipline and regarding those who intrude with deep suspicion (Bird, 2001). As Sayer (2000) observes they are both parochial, ‘the subject becomes the lynchpin of the identity’ (Bernstein, 1971:36) and imperialistic, claiming the territory of other disciplines. What follows are disciplinary communities that not only reinforces specific techniques, methods, exempla, concepts and theories but regard themselves as the holders of a unique knowledge about the world over which they hold rights and for which they are responsible. This knowledge must be guarded. The logic and legitimacy of a discipline is justified by its disciples through control over a unique and exclusive insight into some natural, social or physical phenomenon or group of phenomena. A discipline claims to generate ‘*a* best knowledge’ (Bourdieu, 1981:12) of something. A monotheistic account of disciplines is reinforced replete with high priests, disciples, places of worship and holy texts.

Recognising a discipline’s claim to a domain of knowledge through its social and institutional structures is one part of the necessary account of disciplinary science. The accepted legitimacy of the techniques and methods to understand the world another part. Mention has also been made of the key role concepts and theories play in a discipline’s claim to knowledge. Although very many disciplines will eschew the language of causality, preferring instead to make claims of contingent relationships (Pearson, 1896), mediation and moderation (Pearl, 2018) or the succession (Harré, 1986) between observed empirical instances, causal mechanisms that account for observations in the empirical world but are not necessarily measureable through experimentation are implicit in the concepts and theories disciplines adopt. How this conceptual and theoretical work comes about is rarely recognised in discussions of the features of disciplinary science. It is tacitly assumed that theories are the emergent properties of empirical investigation. But in a post-positivist science (Lakatos, 1978, Lakatos, 1999) such an instrumental account of the generation of theory will not suffice. More recent investigations of objectivity have accepted the place of trained judgement in which the disciplinary scientist must ‘synthesise, highlight, and grasp relationships in ways that are not reducible to mechanical procedure’ (Daston and Galison, 2007:314). Disciplines lay claim to relationships that can only be explained through invoking the psychological insight of the immersed disciplinary expert embedded deeply in the culture of a discipline. As the ethnographer Clifford Geertz (1983:155) explains:

> In the same way that Papuans or Amazonians inhabit the world they imagine, so do high energy physicists or historians of the Mediterranean in the age of Philip II […] to set out to deconstruct Yeats’s imagery, absorb oneself in black holes, or measure the effect of schooling on economic achievement is not just to take up a technical task but to take on a cultural frame that defines a great part of one’s life […]

Causal claims, however articulated, are not only a product of disciplinary expertise in the application of technical procedure. They can only be explained through invoking psychological attributes of the immersed disciplinary expert who explains empirical instances in the language of theory. A disciplinary disciple not only learns a technical trade, they *become* so they may produce highly specific yet problem-portable knowledge. This knowledge is abstract in the sense that it is transferrable or generalizable—dependent on ones epistemological position—not as empirical cases but as theory to explain observed yet segregated empirical instances.

A science as usual account of transdisciplinarity

In his ground-breaking investigation of one discipline, sociology, Abbott (2001:135) observes that 'interdiciplinarity presupposes disciplinarity', suggesting that disciplines are the building blocks of interdisciplinary science, additive in producing new approaches to the investigation of increasingly complex and broader issues. The generally accepted starting point to discuss the subject matter of interdisciplinary science are these problems, and, as noted in the discussion of disciplines, techniques for their empirical investigation, most often based on discipline specific theory.

Typical of this characterisation of complex problems, of disciplines and the rationale for interdisciplinary research is a programme of interdisciplinary research funded through the National Institutes for Health (NIH), a part of the United States Department of Health and Human Services and the government funder of medical research. Building on funding for 21 exploratory centres for interdisciplinary research, NIH established funding for nine interdisciplinary research consortia addressing a broad range of health related research including organ design, genomic drug discovery, geroscience, genome engineering, fertility preservation, neurotherapeutics, neo psychiatric phonemics, obesity research, and stress, self-control and addiction (NIH, 2020). All of which might be regarded as complex challenges requiring insights that transcend the boundaries of several individual disciplines.

The focus of this funding-stream is characterised as problem-orientated, as representatives of the implementation work group clarified (Huerta et al., 2005). Citing an example from the application for one of the interdisciplinary consortia, they note, it would comprise:

> teams of investigators from different disciplines to begin to develop new ways of thinking about, and addressing, significant research problems in research relevant to health and illness.

This consortia are responding to terms of reference published by NIH, which was critical of traditional approaches to health research, characterised as ‘a series of cottage industries, lumping researchers together’ (NIH, 2020). These terms of reference presents a stark picture of disciplinary isolation in which disciplines are presented as unable to communicate with each other and advance knowledge about complex problems. In response to this incomprehensibility between the disciplines, the NIH interdisciplinary programme of research sought to:

> dissolve academic department boundaries within academic institutions and increase cooperation between institutions, train scientists to cultivate interdisciplinary efforts, and build bridges between the biological sciences and the behavioural and social sciences. Collectively, these efforts were intended to change academic research culture […].

(NIH, 2017)

Elaborating this aspiration, researchers from one of the consortia, the Centre for Interdisciplinary Research on Antimicrobial Resistance (CIRAR), undertook an extensive review of over 500 academic publications across education, business and health care in some way related to interdisciplinary research, interviewed interdisciplinary researchers in their team, reviewed definitions of interdisciplinary research and field-tested their results. Their preliminary definition to inform the review methodology can be seen to be firmly rooted in the framing of the research funding programme of which they are part. Although the language slips between describing disciplines and fields, which other authors have seen as distinct (Byrne and Callaghan, 2013), this definition suggests a strategic response to a particular problem in which academic research teams comprise interdisciplinary partners to investigate problems they would not be able to research within their own discipline. This is achieved through mobilising a different armoury of methods and techniques while extending their conceptual and theoretical frame of reference. This initial definitions was:

> Any study or group of studies undertaken by scholars from two or more distinct academic fields, based on a conceptual model that links or integrates theoretical frameworks from those disciplines, using study design and methodology that is not limited to any one field, and requiring the use of perspectives and skills of the involved disciplines in all phases from study design through data collection, data analysis, specifying conclusions and preparing manuscripts and other reports of work completed. (Aboelela et al., 2007:339-341)

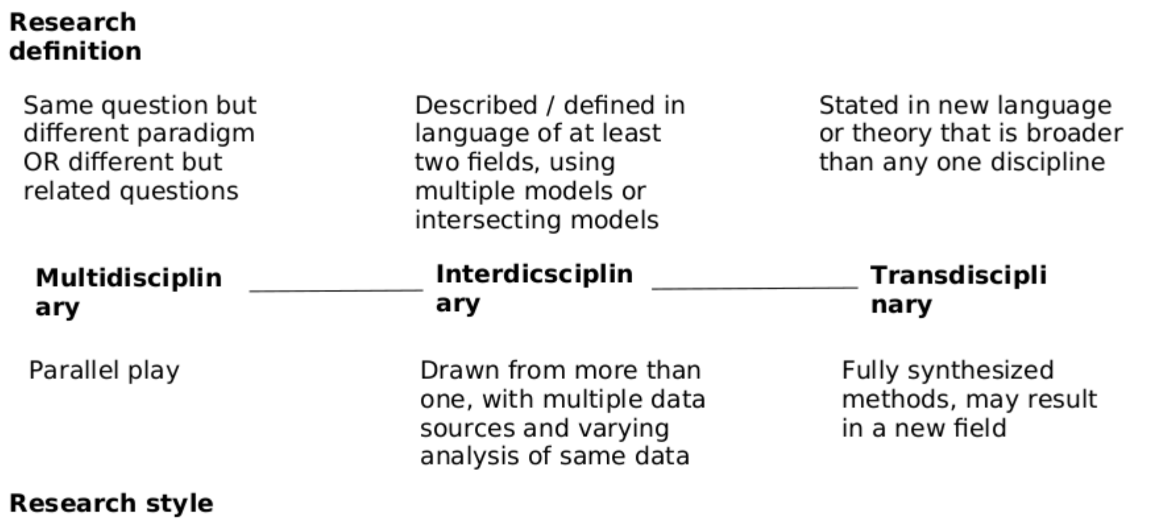

Figure One: A continuum of interdiciplinarity (after Aboelela et al., 2007: 340)

Reporting the findings from their review these authors identified the ways in which language marks out the difference between multidisciplinary, interdisciplinary and transdisciplinary research (see Figure 1). In multidisciplinary research the language of disciplines persists and is unaltered. Interdisciplinary research teams modify their language, others have described these as ‘pidgin’ (Demir, 2011, Galison, 1997), suggesting a simplified or hybrid language. Transdisciplinary science, however, generates a new language equipped to express new concepts. These findings are emphasised through investigation of other features of the modes of disciplinary working identified by Aboelela et al. (2007). Multidisciplinary teams publish in separate publications for their own disciplines; their language implicitly discipline specific. Interdisciplinary researchers seek to adopt a language intelligible to all the researchers involved in shared publications. Transdisciplinary research also shares publications, seeking to adopt a new language in new disciplinary journals.

Research style is similarly shaped through a capacity or willingness to traverse the borders between disciplines with technologies (see Figure 1). Multidisciplinary teams maintain their technical and methodological distinctiveness. Interdisciplinary teams offer their instruments of investigation and analytic tools to a common problem, seeking to bring these diverse insights into conversation with one another. In the continuum developed by Aboelela et al. (2007), transdisciplinary research conjoins methods and analysis to potentially elaborate a new discipline.

This definition of transdisciplinary research is similar to an example offered by Weingart (2010) of the emergence of the new discipline of molecular-biology through interdisciplinary research. As Weingart (2010) observes, molecular biology emerged as a discipline through the systematic application of the methods of physics and biology to the problem of explaining life. This conjoining of disciplines led to the emergence of a discipline equipped with, for Puck (1992), a radically changed approach to biological research that combined quantitative experimentation and highly specific model-building approaches to advance the description, statistical association and predictive models of biochemical genetics.

Aboelela et al. (2007) offer an account of transdiciplinarity located around its observable features. Transdisciplinarity is characterised as the synthesis of method and language. In producing a new discipline it remains firmly located in existing disciplinary relationships and institutions, albeit occupying a new space within these.

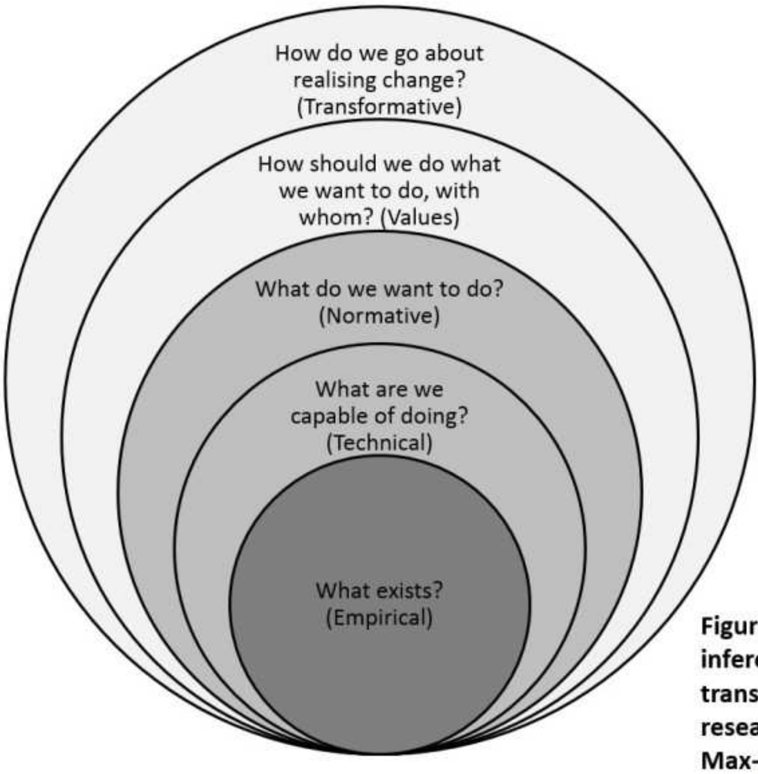

Figure 2: The arc of inference of transdisciplinary research (after Max-Neef, 2005)

In summary, this science as usual account of transdisciplinary science is catalysed through addressing complex problems. The focus is on the generation of new language, theory and technical method within science increasingly capable of addressing what exists in complex problems and offering solutions (see Figure 2). This account of transdisciplinary science is firmly positioned in existing disciplinary relationships that are recursively elaborated with reference to a problem under investigation. New alliances of scientific disciplines are built, supported by institutional funding and by extension research institutions, which in turn lead to the creation of new disciplines. New cottage industries are built to house and promote newly formed networks of researchers held together by their newly formed technologies, specialist language and concepts in new disciplines. They inevitably defend their boundaries within existing institutions of knowledge generation. Methodologically, social actors beyond these boundaries are not considered in processes of knowledge generation, although they may play a role in bringing the technical achievements of this transdisciplinary science 'closer to the market' (Collini, 2012:171). A rather different methodology is needed to understand the potential role of social actors, a pragmatic account addressed in the next section.

A pragmatic account of transdisciplinary science

For methodological pragmatists the dynamic process of the accumulation of scientific knowledge cannot be reduced to advances in technique, method, language, the defending of boundaries between disciplines and the creation of new ones suggested in the science as usual account of transdisciplinary science. Instead, there is an ongoing and decisive revision of knowledge that includes a multitude of social actors beyond the scientific community. Nowotny and colleagues (2001) adopt the European pragmatist and political economist of science Otto Neurath's simile of science, Neurath's boat. This elaborates their account of a transdisciplinary methodology. Scientists, Neurath (1931:620) contends are:

> [l]ike sailors who have to rebuild their ship on the open sea, without ever being able to dismantle it in dry dock and reconstruct it from the best components.

This simile, for Cartwright (1996:92 emphasis in the original) is ‘propelled by an *idea’.* The stock of knowledge of science does not simply keep changing forever to address a problem. This would have Neurath’s boat hove into every available port to be rebuilt afresh, as the science as usual account of transdisciplinary science suggests. Instead a different account of the progress of science is proposed: ‘a decisive revision of our concept of knowledge is required to fulfil its Enlightenment promise’. This is articulated in three ‘holisms’ in Neurath’s conception of scientific practice (Cartwright, 1996:92-93). The first addresses the reciprocal relationship between theory and practice. Unlike the science as usual account of transdisciplinary science that characterise the relations in which theory informs technical practice as a one-way deductive process of inference, in this pragmatic account theory and practice are conceived of as addressing and informing each other: theory informs practice and practice informs theory. This observation is supported through the other two holisms. A theory of underdetermination explains that data does not drive science, it has the status as evidence for some hypothesis or other. Data is always understood in its relation to assumptions that make it plausible and acceptable in the service of a theory or hypothesis under investigation. The third holism ascribes a ‘dependence of thought on antecedent concept formation’ (Cartwright, 1996:93). Put more clearly, scientists do not enter into an area of enquiry a blank slate unencumbered by insight and knowledge. While this *tabula rasa* position may provide a useful account in a positivist science for an objective distance between scientists and the object of their investigation (Daston and Galison, 2007, Glaser and Strauss, 1967) Neurath contends scientific enquiry is always informed by the ideas that precede it. The entanglement of action and theory described in the three holisms keeps Neurath’s boat of science afloat, ‘rendering intelligible the actual workings of reason and, where possible, expose them to conscious intervention’ (Cartwright, 1996:93). Neurath’s boat and its meanings provide a methodological bridge to Nowotny and colleagues’ account of pragmatic transdisciplinary science.

For Nowotny et al. (2001) the simile offers a plausible account for the reciprocal relation between ideas and practice in science. It must, however, be extended in a liberal democracy characterised by the increasing participation of stakeholders—governments, private and third sector organisations and lay-publics—the sea is far more turbulent, the boat holes more often and the patching with available resources on the boat is ever more frenetic to keep it afloat as it addresses social problems.

Driven into the *agrora* (Nowotny and colleagues term for the market place in which science happens), science must engage in contexts of application, maintaining a focus on finding solutions to problems through problem-based knowledge. Science must also include the views of individuals, organisations and institutions who are interested parties with situated knowledge and expertise. These (lay and specialist) experts insist, or try to insist on the evaluation of the efficacy of a problem or a problem-based solution to a problem over which they feel for very many reasons and to various degrees they have ownership. But, while this pragmatic account of transdisciplinary science recognises the market place of ideas and contestation that inform both the identification and potential resolution of problems it remains largely silent on the relations that promote scientific knowledge at the expense of lay and specialist knowledge. It therefore offers little by way of methodological resolution to a central challenge of transdisciplinary science, whose insight is most valued and why.

Investigation of two case studies of lay-participation, reported by Nowotny and colleagues, provide insight into the social relations that undermine or infer credibility to particular kinds of knowledge produced in particular ways in transdisciplinary science.

The first case study demonstrates how transdisciplinary science is hampered through rejecting lay-knowledge because it does not conform to a methodology of science. This is a case study of sheep farmers in the Lake District, a fragile upland eco-system in north-west England described by (Wynne, 1996). A further feature pertinent to this case is the location in the region of a former nuclear generating plant (Calder Hall) and weapons production and research site (Windscale) and now nuclear fuel reprocessing, nuclear waste storage and nuclear decommissioning site (renamed Sellafield in 1981). On the 10th October

1957 a three day fire in one of the nuclear piles at Windscale led to the release of radioactive isotopes that contaminated nearby farmland and much further afield. Subsequently Sellafield and its management have been embroiled in controversies about environmental discharge, accidents and workforce radiation doses (Wynne, 1996). On the 26th April 1986 a catastrophic nuclear accident at the Chernobyl Nuclear Power Plant, near the city of Pripyat in the north of the Ukrainian released radioactive isotopes that once again contaminated large areas of Europe, including the sheep farms of the Lake District. Government scientists were dispatched to monitor levels of radioactivity in sheep and identify strategies to reduce contamination. The legacy of the earlier nuclear accident and contamination coloured the relationship between the farmers and government scientists. As Wynne (1996) observes, the management of the Sellafield site (and by extension government scientists) had a poor public image for openness and honesty. In a number of ill-conceived interventions following the Chernobyl accident scientists alienated the farming population further. This, in itself, is a fascinating account of the gradients of power that exist between scientists and lay-populations and the perceived legitimacy of scientific knowledge over lay-knowledge in decision making processes (see also Williams and Popay, 1994). But Wynne (1996) offers a more nuanced insight into the relation between sheep farmers and scientists in which the farmers retold stories of scientists who demonstrated a profound misunderstanding of sheep and sheep farming and were dismissive of sophisticated knowledge held by sheep farmers. Farmers felt their social identity as specialist upland sheep famers with their long apprenticeship and learned craft of sheep husbandry in a fragile eco-system managed through its adaptive informal cultural idiom to be denigrated and threatened. Meanwhile, farmers' expertise was not recognised 'because it was not formally organised in documentary, standardised, and control orientated ways recognisable to scientific culture' (Wynne, 1996:43). A significant gap thus emerged between lay-knowledge, dismissed as local, cultural, idiomatic and incredible and scientific knowledge as rigorous, credible and generalizable.

While Wynne's study emphasises credibility imbued in scientific method, a second case study provides an account of the ways in which lay-experts may gain creditability and intervene in scientific research. Epstein (1996) investigates what is known about HIV and AIDS and what constitutes legitimate research and treatment in the context of the early emergence of HIV infection and AIDS in the United States of America. His focus, the vast array of actors ranging from physicians and biomedical research scientists, government agencies, pharmaceutical manufacturers and bio-technology companies, health agencies, educators, deliverers and activists, advocacy groups and people living with HIV and AIDS. His case study investigates models of scientific practice, how scientific controversies are adjudicated and the relationships of cooperation and conflict amongst these actors. It is a case that interrogates the 'linkage of power, knowledge, and order forged in […] the context of the AIDS epidemic' (Epstein, 1996:3). This is a study that recognises that no one group of actors—activists, scientists, health providers—has all the answers but brings into focus the competing commitments of scientific expertise and participatory democracy that are the focus of a pragmatic transdisciplinary methodology. Epstein identifies four tactics employed by social activists at the heart of this story to marshal credibility. First, activists learnt the jargon—the terminology of scientists—and cultures of the biomedical sciences and employed these to force scientists to engage with their arguments. Second, people living with HIV and AIDS occupied a privileged position, not only as bearers of knowledge about the infection but also as research subjects. They were an 'obligatory passage point' (Abbott, 1988 quoted in Epstein, 1996:339) researchers had to engage with in discussions about clinical trail protocols. Third, activists often occupied the moral high ground to influence the scientific process employing both the language of science and strategies of politics to insist on ethical and moral positions in research, about gender and ethnicity as examples. Fourth, activists engaged in on-going debates within the scientific community, offering support to one side or another, thus gaining allies. These strategies played to the features of disciplinary science discussed earlier in this paper.

Unlike the sheep farmers, whose knowledge was dismissed as folkloric and traditionalist, the activist in Epstein's study were often considered as generating credible and situated knowledge. They occupied an 'advisory jurisdiction', intervening in scientific contestation about the efficacy of drugs and the causation of AIDS. These are not questions settled through definitive clinical trail or epidemiological study, as Epstein points out. They are settled through negotiation in which credible actors are allowed to interpret the findings from scientific experiments, in which they may well have played a part in designing. Nowotny and colleagues (2001:223) go further, noting that:

> Transdiciplinarity is achieved by focusing on research problems as they emerge in contexts of applications and where the heterogeneity of knowledge producers introduces additional criteria of assessment apart from scientific quality

For Nowotny and colleagues this suggests the epistemological core of transdisciplinary science is hollowed out and replaced with many different norms, practices and legitimate ways of knowing and 'must be sensitive to a much wider range of 'social' implications' (Nowotny, 2001 199: emphasis in the original). Indeed, accounts of transdisciplinary science that cite Mode 2 science as informing their methodology frequently embrace methodologies of co-production and / or participatory methodology (Leavy, 2011). Most often without acknowledging a methodological literature that has engaged with the limits and indeed potential tyranny of participation (Cooke and Kothari, 2001, Collins and Evans, 2002). Only infrequently, it appears, are these conflicts recognised. When they are, the limits to participation are similar to those presented in the cases in this paper. These limits may be expressed as contestation of:

- Values—ontological accounts of fundamental differences of orientation to a problem
- The legitimacy of knowledge—epistemological contestation of diverse knowledge claims by diverse actors.
- Economic and political positions—expressed most often through contesting methodological rigour that leads to claims of credibility of interpretation made from the research.

(after Siebenhüner, 2018)

As Abbott (1988) cautions, the advisory jurisdiction occupied by social actors in transdisciplinary science is inherently unstable 'sometimes a leading edge of invasion, sometimes the trailing edge of defeat'. The analysis of the case studies offered in this section suggest in a market place where complex social problems demand transdisciplinary science the epistemological core of science is not emptied. It is pivotal in evaluating which actors are deemed incredible or credible to science. To extend Neurath's boat simile, a pragmatic transdisciplinary science no longer patches the boat with material available only in the boat, but relies on scientifically credible actors throwing caulk into the boat to keep it afloat to support the decisive revision of knowledge. However, the inevitable contestation of what constitutes a credible science agenda, the rigour of scientific method and what may or may not be valid claims from science are not directly addressed in the pragmatic methodology of transdisciplinary science. Thus, turning to the conceptual model in Figure 2, the methodology of Mode 2 pragmatic transdisciplinary science reaches into but does not transcend the normative domain. While able to interpret what is to be done in any given intervention from the point of view of actors whose voices are heard above the din of the market place and offering partial problem based knowledge a pragmatic transdisciplinary methodology cannot adjudicate explanatory questions of value and transformation. For these a methodology is needed that climbs the ladder from description and interpretation to explanation, laying claim to the cause of things, a realist post-disciplinary methodology.

Post-disciplinary realism

Post-disciplinary realism has the potential to transform science. Methodologically, its starting point is neither the technical data generation of science as usual nor the market place of social actors discussed in the pragmatic account of transdisciplinary science. Instead, post-disciplinary realism has, as a starting point, both problem-focussed and discipline specific theories introduced in the discussion of disciplines at the beginning of this paper and lay-theory, considered in the previous section. Unlike the accounts of transdisciplinary science as usual already discussed in this paper, which is concerned through a flat ontology in describing and interpreting empirical evidence, realism acknowledges a stratified (or depth) ontology. Empirical accounts describe phenomena but they are insufficient to explain the generative causal mechanisms that produce them (Archer, 1998, Bhaskar, 1975). Fallible and provisional claims can be made to explanation of these causal generative mechanisms, which through their powers, liabilities and dispositions shape that which is recordable through the instruments at our disposal. These generative mechanisms are invariably not amenable to empirical enquiry. They are a product of our creative and learned imagination. Although rarely thought of in this way they are the product of *becoming* that characterises disciplinary science discussed earlier in the paper. Through this imagination we produce accounts that offer a best fit to what Mayer and Lunnay (2013) describe as the ‘conditions fundamental to the existence of phenomena’. Unlike the logical inference of deduction that moves in a linear progression from basic premise to conclusion through experimentation, relying on methods and data, the inference described in this realist methodology is a dialogue between evidence and ideas (Ragin, 1992, Emmel, 2013). This requires both abductive and retroductive inference.

Abduction, ‘the creative inferential process aimed at producing new hypotheses and theories based on surprising research evidence’ (Tavory and Timmermans, 2014:5) was developed by the American pragmatist Clifford S. Pierce. A semiotic triad of meaning-making is proposed that includes a sign, an object and an interpretant. The sign, a signifier of something as smoke signifies fire, always exists in relationship to something, an object that is an actual thing. Tavory and Timmermans point out that the object might be thought of broadly, it might be something material like a fire or a person. It might also be a word or idea. This relation between a sign and an object is an uncomplicated empirical account. The key insight of abduction is the meaning-making entailed in Pierce’s neologism, the interpretant: ‘a transformation that the interpreter undergoes while making sense of a sign’ (Tavory and Timmermans, 2014:23). This abductive inference fits with Neurath’s three holisms, which like Nowotny and colleagues ‘hollowed out epistemology’ is anti-realist. As a methodology of inference it assumes reality as given to us in experience in a continuum capable of being differentiated in an infinite variety of ways by an infinite variety of actors. Realism diverges from this constructivist position, contending that the real exists, but it is independent of our knowing it.

While abductive inference is inherently anti-realist it is adopted in realist research because its structured method of data collection and analysis lends transparency to the theory-driven methodology of inference used in realist research (Mayer and Lunnay, 2013). This method of inference is retroduction, which Bhaskar (1975:125) notes is the:

> theoretical redescription, so that theories of the various kinds of mechanisms at work in the generation of the event can be brought to bear on the event's explanation.

This is a radical departure from transdisciplinary science as usual and the pragmatic methodology of transidiciplinarity. It is a method of inference that explicitly lays claim to cause.

Rachel Carson's ground-breaking book Silent Spring, provides an instructive account of this retroductive inference in action. While researching and writing Silent Spring in the early 1960s, Carson penned a letter to the physician Morton Biskind, who with Irving Beiger had co-authored a case report "DDT Poisoning: A New Syndrome With Neuropsychiatric Manifestations".

> Recently some of my thinking on [the relationship between pesticide use and increased cancer rates] has begun to fit together like the pieces of a jigsaw puzzle […] a great light is breaking in my mind

The acclaimed ecologist and environmental activist Sandra Steingraber observes in an introduction to a Library of America edition of Silent Spring (Carson, 2018) how Carson had an 'uncanny ability, when she discovered gaps in the data, to see across to the far shore'. She considers this to be extrapolation of the data. As she notes, so many of the methods and data to support Carson's hypothesis did not exist when she published Silent Spring in 1962. Carson did not have access to state level cancer registries (c. 1970-90), a working model of endocrine disruption (c.1996) or epigenetics (c.2008). The first Landsat satellite to acquire imagery of the earth was not launched until ten years after Silent Spring was published.

Steingraber's discipline is ecology. Her work is that of an environmental scientist, an interdisciplinarian who brings the methods of natural, social and physical scientists together in productive engagement. Her interpretation of the way Carson thought about the relationship between pesticides and cancer exemplifies her methodology. Her focus is, like in the account of transdisciplinary science as usual, focused on method and data. For

Steingraber it is the reproducibility of methods and the extending of trends in the data that guide Rachel Carson to the far shore.

A realist post-disciplinary methodology interprets Rachel Carson's inference differently. Carson, a consummate wordsmith, is not concerned with method and data alone, she is talking of ideas. Her letter to Morton Biskind conveys the epiphanic; a revelatory moment when the empirical data she has amassed fits with a theory she has been working out in her head. Carson's 'great light' is what Basarab Nicolescu (2002), the author of the Manifesto of Transdisciplinarity, describes as a 'big bang moment'. A moment when we take the step from testing hypotheses through empirical science to gaining an explanation of the present world that is beyond empirical measurement. Through retroduction ideas and evidence are brought into a successful dialogue.

As was argued at the start of this paper, disciplinarians address these causal questions (although they will frequently eschew this language) to reproduce problem-portable knowledge in their disciplines. However, instead of valorising technique and method and assuming there is a constant conjunction between data and findings in empirical research, as is common in accounts of science as usual, a post-disciplinary realist methodology argues it is the interpretation of these experiments negotiated and renegotiated in a language beyond disciplines that drives forward scientific knowledge. Disciplines are characterised by both verbal disputation and experiment as argument (Campbell, 1969). Explicitly, post-disciplinary realism, intent on causal explanation and laying claim, however partial and fallible, to how we should do what we want to do with whom and how change might be realised (see Figure 2), adopts this praxis in its methodology. With these methods of inference and methodological principles considered the final section sets out schema for a post-disciplinary realist methodology.

A conclusion: a schema of a methodology post-disciplinary realism

A realist methodology is ontologically stratified and epistemologically constructed of the fallible theories expressed in the disputation between ideas and evidence (Maxwell, 2012). This methodology is theory driven. Its inference, retroduction. However as Mayer and Lunnay (2013) note, a central critique of this theory-driven inference is its inherent bias; research and its analysis set up to confirm pre-conceived theory that ‘cannot logically identify the unintended artefacts of empirical data’. Retroduction cannot stand alone as a method of inference. This paper follows Danermark et al (1997), Meyer and Lunnay (2013) and Parr (2013) in proposing abduction as a necessary (although anti-realist) associated method of inference. Neurath’s three holisms pertain—the impossibility of the *tabula rasa* (or blank slate) investigator; a reciprocal relationship between theory and practice; and data as evidence to test hypotheses. They are the stepping-off as opposed to starting point of a post-disciplinary realist methodology. Following Archer (1998) this methodology recognises scientific research reproduces and transforms knowledge already made. Figure Three, a zigzag (after Lakatos, 1976) of a realist post-disciplinary methodology, thus starts and ends with dashed lines. These represent the human praxis that has made and will make science (and other forms of human knowledge) that precedes and supersedes the current investigation. The *tabula rasa* scientist is replaced with an investigator imbued with bundles of hypotheses that relate to segregated observations, which Boudon (1991) describes as theories of the middle range. These may arise from a wide range of sources of expertise from scientific experiment to the localised expertise of Lake District sheep farmers or people living with HIV/AIDS, the examples discussed in this paper. The criteria for the inclusion of their expertise is not rigour of method and the adoption of scientific language and politics but the value of insight to the writing of hypotheses to be investigated in research. A hierarchy of evidence, which derives its claim to objectivity in relation to the distance produced through method between observer and observed, is flattened.

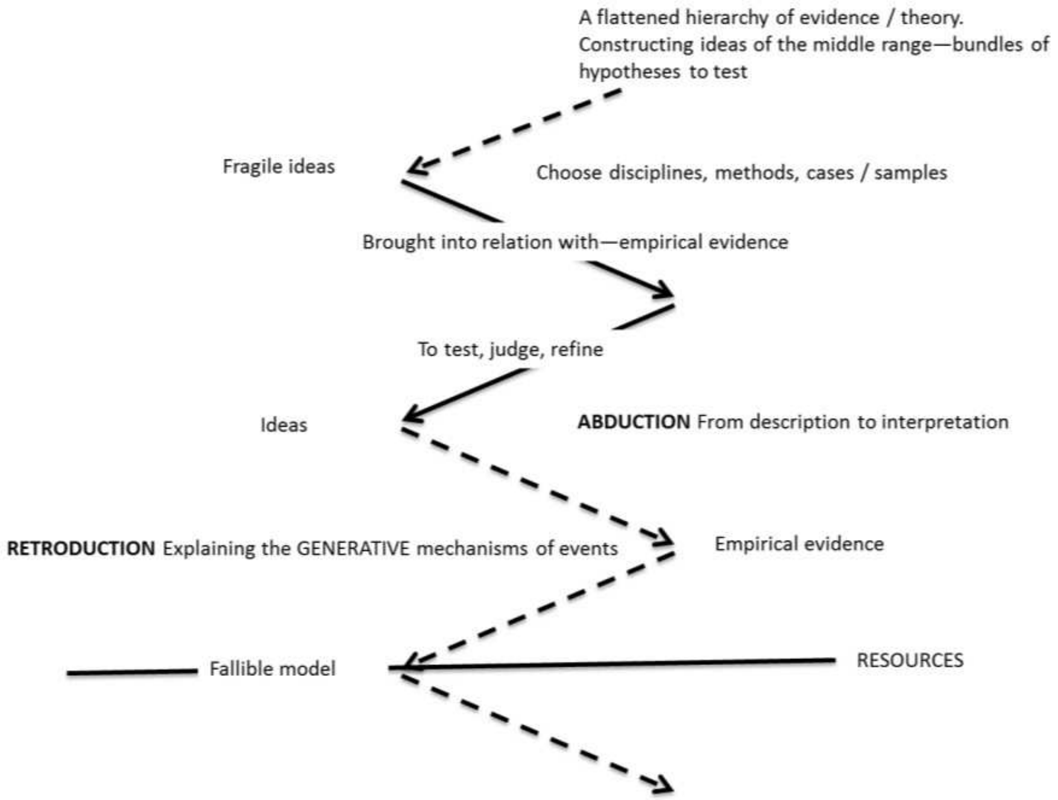

Figure Three: A schema of the zigzag of post-disciplinary realist methodology (after Lakatos, 1976; Emmel, 2013)

These theories of the middle range are weak constructions; fragile ideas to be tested and refined through verbal disputation and experiment as argument. Yet they are strong enough to be located in disciplines, to choose methods, cases and samples for their investigation. Disciplinary disciples, I have argued, in their technical apprenticeship and becoming apply creative and experimental inferential processes to produce new evidence and re-describe problems theoretically to account for the generative mechanism that explain them. A post-disciplinary realist methodology is driven by the ontological depth of disciplinary knowledge that makes explicit ideas and their connections. Its concern is explanation (see Figure 1). To achieve this it is neither hemmed in by the walls built around disciplines nor the imperialist incursions made into other disciplines. A post-disciplinary realist methodology is far more expansive and coherent than institutionalised disciplinary science.

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