Materiality Methodology, and Some Tricks of the Trade in the Study of Data and Specimens

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In recent years we have witnessed a revitalized interest in the study of materiality within social, organizational, and humanistic scholarship. Programmatic calls to attend to materials, things, and objects, and their entanglement with practice have been issued in a range of disciplines. These reexaminations of materiality often position themselves as a corrective to approaches that overemphasized rhetoric and discourse, or that treated “the social” as an abstraction or idealism. For STS, however, materiality is not altogether new, but rather a long-standing theoretical and methodological topic that investigators have wrestled with since the founding of the field. In the past three decades, STS has examined concepts such as *objects with agency*, has followed the *turn to practice*, and has considered *artifacts that have politics*. Such propositions have always been accompanied by lively critique from, for example, social constructivists or adherents of the strong program who, in various ways, have accused materialist analyses of falling into the traps of naïve realism or technological determinism. Throughout these discussions, and on both sides of the fence, the best STS work has retained a staunchly empirical commitment even as it has engaged these thorny conceptual questions.

STS has come to some useful conclusions, contentious though they may still be, about materiality along the way, particularly in the realm of methodology; that is, how do we approach studies of things, objects, stuff, and materials, their agencies and interrelations, in action and across time? In this chapter, I will exposit four methodological threads that have practically influenced my approach to studies of materiality, and from these I distill four “tricks of the trade” that have helped me investigate materiality as encountered in the field. Recounting tricks of the trade is never a comprehensive endeavor, and there are always more tricks to be exchanged. In this essay there is room for only four, one for each intellectual thread. Thus, the goal of this essay is neither exhaustive nor theoretically synthetic, but rather the beginning of a conversation for how to facilitate empirical investigations.

The overall argument will be that materials must be encountered specifically as one goes about research. I use the word “materiality” because it is the current term of art, but in actuality it makes me somewhat uncomfortable, particularly as the banner for a movement or common field of inquiry. This is because I feel there is very little that can be said about the topic of "matter," as such. There is just so much of it, it comes in so many forms, and it plays so many changing roles over time. And yet, a great deal of current social and philosophical scholarship about materiality is pitched in a high and abstract register, often foreclosing further study with sweeping declarations about the nature of materiality. Rather, materiality is an ongoing interest within and among various topics of study; its investigation should be specific, situated and tied to research questions at hand rather than cast as an investigation of materiality in general; and our methodologies should allow for the surprises of fieldwork to emerge rather than foreclose the discussion with received categories for the role of the material.

This is why this chapter revisits the craft and method for how to study materiality: How to make it something available for inspection in the social and humanistic disciplines? How to recount findings meaningfully? And, when should materiality be foregrounded in an analysis rather other topics? This chapter will outline methodological approaches from four intellectual threads: ethnomethodology (Garfinkel et al. 1981); the anthropology of classification, similarity, and difference (Douglas 1986); actor-network theory (Latour 1988); and historical ontology and epistemology (Hacking 2004; Daston 2000). It is not possible to recap these traditions or debates in this chapter, and so instead I will draw out threads from classic works that have informed my approach to materiality—works that have also served as key points of dialogue between these traditions over the years. At key junctures these traditions have been in dialogue with each other, sometimes in a relationship of critique, and at other times of theoretical elaboration. Each has offered a useful orientation to investigation (methodology), and from each I will pluck a maxim, or what Howard Becker called a "trick of the trade" (Becker 1998). Posed as method and methodology, these "tricks" will not cohere as a theory—that is, I am not proposing an analytic or theoretical synthesis of ethnomethodology, ANT, and the other traditions. Rather, I emphasize the utility of a syncretic toolset, and the value of having multiple handles to investigate the issues of materiality. Theoretical coherence (or not) is a matter for the downstream arranging and recounting of findings.

Some of these tricks were formulated by their authors as principles, or even metaphysical postulates, but here I present them as methodological aids. Many of the tricks specifically "reset" the researcher, enabling an escape from received understandings of the material, or from a predefined role for their agencies; thus, some of the tricks have the role of encouraging an *ethnomethodological indifference* or an agnosticism to what materials "really are," and to how they must be approached through investigation. The goal of starting from an agnostic position (itself a trick) is to enable the investigator to find unique configurations of the material, the natural, the technological, the social, and their hybrid or entangled combinations in the research object at hand.

At issue in this digitalSTS volume, and more broadly in studies of materiality, is the question of how to investigate the digital. Is it something new, requiring inventive theoretical formulations, methods, and a reorientation to our objects of study? Or is it a continuation of long-standing themes, such as agency, standardization, and immutable mobility? For STS, the recent interest in materiality, particularly materiality of information or the digital, is a contemporary inflection to long-standing theoretical and methodological topics. This chapter won't begin from the premise that "the digital" and/or "the material" are particular kinds of concerns for STS. Instead, I argue that the investigator must "discover" the digital and/or material through fieldwork.

Throughout the chapter I will draw from examples of the production, storage, and use of blood and river water samples and their entangled data as they circulate among scientific practitioners. I have found that sometimes data are "quite digital," stored in hard drives and transferred across networks, but at other times data never become computational, preserved only as chicken-scratched notes on paper forms archived in file folders. Mostly, specimens display properties we associate with physical objects, such as archived blood aliquots that are treated as finite resources to be used sparingly in research; but sometimes blood is enacted in ways that display qualities we associate with digital materials, such as DNA amplification or creating immortalized cell lines, that is, a potentially indefinite "copying" of materials. Rather than making general claims about the digital or material (theory), instead I will outline the results of treating the materiality of data and specimens as something to be discovered relative to empirical investigations (methodology).

A final point before diving in: One of the leading recent invigorations of materialist thinking (but not, I think, research) has emerged from a variety of brands of *new materialist* philosophy. While occasionally I have gained some philosophical insight from reading these new materialist texts, I have never gained a methodological insight, and so I say nothing more about these lines of thought herein. Here, I side with Latour's response to Graham Harman's demand for metaphysical generalizations beyond specific research: "the empirical is not disposable" (Latour et al. 2011). This is an assertion that *if* there is a metaphysics to be uncovered it is immanent rather than transcendent. Materialist thinking and research, such as within organizational theory (Orlikowski 2007), has been more germane to my interests with its commitment to concrete research. But it has also been plagued by hard and fast assertions about materiality and its agencies, often limiting investigations to "technology," for instance: "As people approach technological artifacts they form particular goals (human agency) and they use certain of the artifact's materiality to accomplish them (material agency)" (Leonardi 2012). The tricks I outline here are intended to forestall such starting declarations; they instead open avenues for situated and specific research rather than closing down investigations with predefined categories, agencies, or roles for materials.

Data, Blood, and Water

I approach these questions through my recent investigations of data and sample archives within scientific research investigations. Should we make a distinction between these two fundamental materials of science: specimens and data? I draw from two case studies that I have written about extensively: the Multicenter AIDS Cohort Study (MACS) and Long-Term Ecological Research (LTER). For simplicity these are characterized here as two longitudinal data and sample collection ventures, but in other texts I have written of the MACS and LTER as "research infrastructures" (Ribes and Polk 2015; Ribes 2014): these organizations do a great deal more than build long-term archives of data and specimens, but I will only focus on those aspects here.

Since 1984, the MACS has been generating data and specimens from cohorts of gay and bisexual men; every six months the men return to a clinic to undergo a medical examination, fill in behavioral and demographic questionnaires, and donate multiple specimens. I will mostly focus on blood, but many other specimens are also collected. The data are collated in archives, and the specimens are kept in cold storage—for both, MACS members seek to render these resources available for reuse in ongoing or new scientific investigations. Similarly, since 1980, LTER has been collecting data and samples from a distributed network of ecological sites across the globe. I will focus on the collection of stream water data, along with stream water samples from their Baltimore County site in Maryland. These data and samples are also placed in archives that are made available for scientists to repurpose in their investigations.

I "cut my research teeth" on ventures that collected no specimens, but rather were exclusively focused on data, their interoperability, representation, or manipulation. This is a central feature of the "cyberinfrastructure" projects that were my empirical cases during the 2000s: all of which defined themselves as primarily concerned with the circulation and reuse of data (Ribes and Lee 2010). Consequently, when I began my investigations of the MACS and LTER, I initially treated those organizations as data-centric enterprises too. It took many months of fieldwork for me to attune myself to the sample archive that they had been building alongside data repositories for many decades. As an STS researcher, I had certainly been aware of the material practices of sample collection in each venture, but my tendency was to treat blood and water as steps in a long translation chain that would ultimately end with their representation as the (never quite) immutable mobiles called data (Latour 1999), that is, I followed my actors to the sites where river water was collected in bottles, then trucked to a laboratory where silt was filtered, and trucked to another laboratory where they were assayed for the presence and concentration of various chemicals, ultimately recorded as data. And certainly this is the case for a significant portion of the blood and water that is collected: within hours or days these materials are subjected to one assay or another, and recorded and preserved as data—for example, salinity, calcium, HIV serostatus, white blood cell counts, and so on. But the samples are *not only* a step in a translation chain to data. For these ecologists and biomedical researchers, samples are an invaluable resource unto themselves. Ecologists travel to the vast cold rooms of the Cary Institute in Millbrook, New York, to visit these repositories in search of decades-old water samples: a vial of water collected from Gwynns Falls in 1995, or perhaps a longitudinal cross-section of samples from 2001 to 2009 from Herring Run. They may seek out these samples for many reasons, such as to search for a chemical or organism not yet recorded in their databases, or to reexamine the samples using a more sensitive or reliable instrument. In 1985, following the discovery of HIV and availability of the antibody test, MACS scientists returned to their archive of blood to search the stored serum for signs of the virus. No scouring of the databases could have revealed this new entity in the data archive; only by returning to the sample repositories with new instruments could these new ontological entities be enacted across the past.

The rest of this chapter will exposit four methodological threads in STS, and for each thread return to these two scientific materials—data and specimens—to illustrate an empirical examination of materiality. Are digital data and material specimens fundamentally different things? Or, perhaps, are they fundamentally the same if considered differently? Is one more material than the other, presumably specimens, or should we approach them as equally material? Or, should we consider each to have its own distinct materiality? Though these are good starting points, ultimately I reject the premises of all these questions. I argue instead for a situated, speculative, and historical approach to materiality. I have found that some actors approach data and specimens quite similarly, and that others treat them completely differently; that the treatment of their material nature has changed drastically for both over the years; and that both data and specimens reveal emergent, open-ended trajectories for their use, limits, and replenishment as resources for scientific investigations.

Ethnomethodology: Interactionism at the Emergence of an Object

Our starting point will be Garfinkel, Lynch, and Livingston's ethnomethodological study of the "discovery" of a pulsar (Garfinkel et al. 1981). An arbitrary starting point for certain, but one that has been particularly impactful within STS for investigating the emergence of new phenomena and their enactment as objects. Here, scientific objects are the hard-won outcome of actors' practical work and negotiation, with materials as the pliable but constraining resources that enable them to do so. The authors do not insist on any particular status or role for materials, those are topics for the actors to practically work over.

Using a tape recording that had been running during the 1969 process of "first time through" discovery Pulsar NP 0532 in the Crab Nebula, the authors outlined how scientists inspected data, evaluated the positioning and calibration of instruments or modeling tools, and over time came to shape an object that could be accounted for as distinct from the circumstances of its discovery. Garfinkel, Lynch, and Livingston likened the activity to a figure-ground gestalt shift in which, from an image filled with foliage, an animal was extracted; or perhaps in a more apt metaphor, they recount the discovery of the pulsar as a "potter's object" which is slowly, methodically, but not deterministically crafted from a simultaneously constraining and enabling material.

A more nuanced term they use for "discovery" of the pulsar is "first time through" (Garfinkel et al. 1981, 134), referring to the challenge of trying to find when one does not quite know what is sought, or how it will manifest. While a pulsar had been theorized in astronomy, and research had already indicated where to look for some of its features using investigative techniques and instruments, no one had yet actually found a pulsar by working their way through scientific materials. How will such an object manifest itself *as* data? Their answer is that the pulsar is not an object at all at the beginning of the night but rather that "somehow it was 'evolved' from an evidently-vague 'it' which was an object-of-sorts with neither demonstrable sense nor reference, to a 'relatively finished object' over the period of the night" (135). The "somehow" is what the analysts explore as a matter of the practical, local, and negotiated inspection that the astronomers engaged in using the materials at hand, including the data, the positioning of the instrument (i.e., the telescope), various visualization tools such as the oscilloscope, modeling tools and their settings.

Only near the end of the audio recording are Garfinkel et al. willing to concede that the pulsar is "in hand" as a distinct object. Early in the evening the object is "witnessably vague"—that is, it is discussed and posited but remains an "it" rather than "the pulsar"—whereas by the end of the night it is a "relatively finished object" (157). By the time of publication of the scientists' findings, "the work of the optically discovered pulsar's local historicized production is rendered as the properties of an independent Galilean pulsar" (134), that is, an autonomous thing existing prior to any method or activity of its detection and that is causing its inscription as data through the astronomical instruments. Rather than "first time through," it was now possible to render an account of the pulsar as "the-exhibitable-astronomical-analizability-of-the-pulsar-again" (135).

The term "material" appears several times in this study of the pulsar's discovery, but never in the sense of *stuff and things out there*; rather, materials refer to the practical at-hand resources that are, in time, enacted as visible, workable, and accountable features of the pulsar in the lab. That is, printouts of data, diagrams, the various instruments, and their calibrated arrangement—these are some of the local materials upon which the pulsar's enactment in situ, and eventually in formal print, depend. This is a definition of materials later adopted by the actor-network theorists (Latour 1986; see esp. Camus and Vinck in this volume). The pulsar of Garfinkel et al.'s study was achieved through practical manipulation of many local resources: data and visualizations, instruments, and the coordinated interpretive work of multiple scientists. In the final scientific publication, these remain only in the traces scientists provide in their formal methods write-up, while the pulsar is presented as independent object in the world. But in the lab that Garfinkel et al. inspected, the pulsar could be "found" only by placing the various materials in a just-so relationship to the other, and at the beginning of the night, in its "first time through" it was unclear exactly how this should be done. Both data and object were emergent, their relationship was interactionally built-up and built-together in the process of discovery.

Example: The (Seemingly) Endless Discovery of the Value of Data and Specimens

I turn now to the data of the ecological research infrastructure LTER. Rather than being the materials for crafting a single object, some of these data have played that role multiple times for distinct scientific objects. These data have in various ways been enacted to stand in, or mean, different things for different kinds of studies. Hidden in the past, these activities remain only in traces such as publications, but at some past point data, instruments, and vials of water were enacted as the accountable and observable objects of ecology. It is by placing materials in different relations to each other that LTER has supported the investigation of thousands of distinct objects over its thirty years, often using "the same materials" for highly heterogeneous purposes (this is a key quality of what it means to approach LTER *as a research infrastructure*).

No datum or specimen is meaningful on its own: they gain and maintain their value by the enacted and sustained links to other materials. For instance, by combining temperature data from the Gwynns Falls watershed and assays of river samples, ecologists have examined "how stream temperature affect phosphorus concentrations" (Kaushal et al. 2010). By combining *that same river temperature data* with those from other catchments they have studied "riparian ecologies" (Groffman et al. 2003). And by using stream flow data along with the *same temperature dataset* they have modeled "impervious surface drainage" (Kim 2007). What objects can be crafted from the data and specimens, and how those objects will be revealed from those materials are ongoing questions for these ecological researchers. Over time new uses are developed for old data and specimens, an unfolding "purpose" for LTER's data and specimen archives.

Some of these data and materials come packaged together, or entangled: it is worthless that a data point for a stream reads as “27 degrees Celsius” without the additional data that tell us what from what catchment (Gwynns Falls) and when (April 7, 2011) it was collected. Much more is collected at the same time—observations about the smells, the turbidity, and the height of the water—and all of these must be kept together in the paper tables that ecologists use to generate their data. As these on-paper data points wind their way to digital databases, these relations must be preserved. There are several check points to ensure this is the case, including, beginning in the late 1980s, the automated alerts that appear if values are entered outside specified ranges, or if a database field is left blank. Similarly, a sample of water is always entangled with the data (or “metadata”) that tell of when it was collected and from where. Through those key points, a sample is linked to the vast array of data that were collected with it, or that come from “the same” source over time. No matter how well physically preserved a sample of water may be, its value also depends on sustaining those links of reference: a desirable and necessary entanglement that information managers and specimen archivists seek to preserve.

Approached in the abstract, there is little to say about the materiality of LTER’s data or samples, in part because that materiality is at stake in their use. For instance, salinity is not a stand-alone material property. That is, whether a particular data point can be treated as a direct stand-in for salinity, or whether that datum must be modeled relative to broader temporal patterns of salinity, or questions about whether the instrument used from that reading was properly calibrated (and so on) are matters for the actors to debate, negotiate, and come to some form of agreement (or not). Across the decades of data collected on salinity in Gwynns Falls, and the scores of uses for those data, we will find many enactments of the materiality they call “salinity.”

Trick of the Trade I: Place Yourself to Observe People Interact While New Materials, Objects, and Things Are Emerging, Negotiated, and Agreed upon (or Not)

For research technologists and scientists, new things, materials, and objects are “hard won” (Daston 2000) and those wins are very often not once-and-for-all; they may recur in later uses of those materials, or through reapproaches to those objects. That said, even the most hard-won objects or materials are often later treated as a given, or blackboxed. Scholars of objects, materials, or things should place themselves “where the action” is of discovering, negotiating, and renegotiating materiality. This can be done through participant observation, or through clever archival reconstructions, but they are rarely visible in the tidy texts of scientific publications or interview-based reconstructions.

Scientists, engineers, and others kinds of actors put a great deal of effort into discovering and understanding materials and objects. Following from the general ethnographic maxim to “respect your actors,” the first trick of the trade is to approach the work of those you are investigating as interactional, and the materials as emergent and relational. The cases of the discovery of the pulsar and the reuse of data and specimens in LTER are two examples where actors are involved in an ongoing process of investigating the properties of materials and crafting objects. The investigator need not decide “what are materials,” and is usually not in a good position to do so; the actors themselves are working away on the topic, using the tools of their own trades. They do so in time, in practice, and in changing relations with each other and the materials at hand. As we have seen in the case of the pulsar, materials are often left behind in favor of sought-after "facts or findings" of investigations, but as we have seen with LTER, actors may return to those data and specimens as they "recur" in new investigations (Rheinberger 2000). Approached in this manner, no material can be taken as having a forever closed meaning, property, or affordance; in principle they can be, and often are, revisited, repurposed, or rediscovered (leading to the fourth trick of the trade: historicism; see below). For the investigator, the key is to be at the right place and the right time, whether that be in person or establishing copresence through documentation.

Anthropology of Classifications: Similarity and Difference Are Institutions

As Mary Douglas wrote, "Nothing else but institutions can define sameness. Similarity is an institution" (Douglas 1986, 55). She was writing specifically of categories, but the point can be extended for the "sameness" of materials, practices, or the fittings of technologies, whether that of plugs or ports, or code and categories (Bowker and Star 1999). Difference too is an institution: things are kept apart and distinct as a matter of routinized activity, or through the sustained activity of classificatory devices. More vivaciously, Henri Bergson puts to us "it's not enough to shout 'Vive the multiple!'; the multiple has to be done" (quoted in de la Bellacasa 2012). Finally, similarity and difference are often a matter of nuanced and situated commensuration (Espeland 1998), as things may be the same for some purposes and different for another.

Example: Can Robots Step in the Same River Twice?

In "Data Bite Man" (2013), Steve Jackson and I recounted how LTER ecologists attempted to transition the by-hand collection of water specimens to an automated robotic system. Their hope was that by installing devices that regularly "sipped" river water, ecologists could cut out the weekly trek to collect these specimens, thus reducing labor, cost, and time, and perhaps adding a layer of objectivity by removing human variation (Daston and Galison 1992). However, they found that the automated system collected water samples in a very different way than people, that is, by pooling weekly samples of water rather than keeping each sample separate as ecologists had done since the inception of their project. This key difference in the practice of a human and a robot rendered the comparison of a decades old legacy archive with the new samples challenging, if not impossible. A deliberative process among these scientists deemed the two methods to be too different, and the loss of historical commensurability with their sample and data archive unacceptable. Today these ecologists collect water both by hand *and* via robot, now two longitudinal sample and data repositories that serve distinct scientific purposes.

The institutions of difference and similarity may be sunk deep into the architectures of data and sample production. For the analyst this may mean attending to the seemingly trivial work of maintenance that sustains similarity, such as metrological practices that make sure temperature data are the same via regularized instrument calibration (O'Connel 1993). When I accompanied and participated in water temperature measurement, even more mundane than calibration, I was instructed to stand in the middle of river and to position my body downstream of the thermometer to ensure my own body heat would not warm the water and distort the reading. This is a colloquial, embodied standardization that any graduate student who collects river samples and data in LTER learns so as to ensure that all materials are collected in the same way, over time (Goodwin 1994). Such a production of sameness is not recorded in any ecological paper I have read, but when I have recounted this story to ecologists, they sagely nod in recognition.

The generation of water samples can be compared to those of blood specimens, but at a granular scale of analysis the practices are unique. The MACS is geographically distributed across four US sites: Baltimore, Chicago, Los Angeles, and Pittsburgh. At each site they have a lab for the analysis of their locally collected biological specimens. However, the practices and technologies at their labs are forever threatening to diverge; for example, samples are left out of the fridge at differing times or technicians may handle them differently. To ensure that the results of an assay are the same at all sites, they often purchase the same brand, make, or model of reagents and instruments (a further proliferation of materials, see irreducibility below), and share protocols for their use across the distributed geographic locations. On occasion, the same specimen of blood is circulated across these geographically distributed sites to be tested by each instrument assembly there—results are compared at the level of practice, instrument calibration, and assay outputs. The "same" blood specimen—sustained as such by packing it on ice in its travels from Baltimore to Chicago—serves to evaluate practices and instruments that ongoingly diverge, but by calibrating them in this manner assays can thereafter be taken to produce comparable results of different blood samples. Here, the blood specimen that is circulated across sites ceases to be an object of inquiry (our usual understanding of the role for specimens), and instead becomes part of the instrument assembly, ensuring calibration, or "sameness."

Each of these practical and technical regimes seeks to ensure particular "samenesses" or mark meaningful differences. Tied as they are to distinct interests and concerns of scientists, one scientist's routine for ensuring sameness is often not sufficient for another. In a common *infrastructural inversion* (Bowker 1994) scientists and technicians may return to inspect the protocols of data and specimen collection and preservation to evaluate these according to their needs, and on occasion these protocols are changed to meet the criteria of emergent instruments and objects.

Trick of the Trade II: When There Are Claims That Things Are the Same or Different, Seek Out the Work and Technologies That Make Them So

When things fit together—whether interoperable data or physical modules—seek out the practices and protocols that hold together these fittings. Often this requires digging into the histories of standardization or interoperability. Similarity is always sustained in the present, but the complications of its routinization may have been worked out in the past (Ribes 2017). This general methodological point is valuable for the inspection of data, widgets, or classifications, though how similarity and difference are established and sustained is always by specific means that demand a close practical and sociotechnical investigation.

If similarly and difference are sufficiently institutionalized, one may also find that the actors have developed ways of testing or revisiting them: for example, as we saw above, the MACS has developed an extensive calibration regime that, every few years, seeks to confirm the similarity of practices and technologies that lead to the generation of data and specimens. All institutionalized regimes of standardization display such occasional infrastructural inversions, and, as with any such inversion, tends to produce a significant paper trail. Whether as an ethnographer following these inversions live or historically reconstructing these practices (ideally, both), inversions offer opportune moments (i.e., observable practice, and paper trails) for the investigation of the production of sameness and difference.

The Irreducibility Principle

As Latour states (rather than finds), "Nothing is, by itself, either reducible or irreducible to anything else" (Latour 1988, 153). No entity on its own can substitute for another, such as electromagnetic waves for the experience of a sunset. In some circumstances, the electromagnetic explanation *stands in* for the world, but when that is the case one will also find a great deal of (often backgrounded) work, and many artifacts to make that the case and to sustain the link of reference. Latour quotes Whitehead in support: "For natural philosophy everything perceived is in nature. We may not pick and choose. For us the red glow of the sunset should be as much part of nature as are the molecules and electric waves by which men of science would explain the phenomenon. It is for natural philosophy to analyze how these various elements of nature are connected" (Whitehead 2013, 29). The electromagnetic explanation is certainly not "wrong," per se, but it also does not substitute for an experience of the sunset—together, the scientific explanation and the experience of the sunset add to the richness of the world. For the philosopher, like Whitehead, exploring how the elements of nature are connected becomes his professional task; for the actor-network theorist, the empirical task is investigating how links between the scientific and experiential spheres are created (or not), and sustained.

The maxim is known as the "irreducibility principle" and is akin more to a metaphysical assertion than a methodological approach. But I have found irreducibility a useful starting point for investigations, serving to sensitize me to the production of additional materials and the work of generating and sustaining more links of reference. As with sameness and difference of materials, the reduction of one material to another requires work and technique, and that work is inspectable as practice and action.

Example: A Generative Approach to Materials

Irreducibility leads to a distinct exploration of data and specimens. Data are not (only) "representations" of something else: a reduced or more essential capturing of the world that is thereafter able to substitute for it (as with recordings of electromagnetic waves from a sunset). Instead, each data point and each specimen can also be considered as something new in the world: *a generative model of data and specimens*. Rather than (only) reducing materials, they proliferate them. In and across vials, refrigerators, files, or disks, these entities thread through their own lives. Data and specimens have properties unto themselves *qua* data and specimens, and they must also be sustained as such along with their ties of reference.

In any longitudinal collection endeavor, as with LTER, each data point or specimen is not a replication of the previous data or specimen, it is a new collection, capturing a river that is warmer or colder, with a changing salinity, and potentially a new chemical or biological composition. Each is a novel temporal slice. This is one reason that these scientists continuously return to the river to collect new materials: if data could fully capture a river's properties they would not keep samples; if samples could stand in for the river they would not return weekly to the river for more.

Similarly with the MACS: blood, on the one hand, is certainly not the whole of the person, but through blood—its analysis as a specimen or its preservation as an aliquot—one can do innumerable new things that cannot be done with the person. Scientists can store it for later retrieval to search for things today that could not be found then, they can return to reinspect it for errors in analysis, or manipulate it to produce altogether new materials such as serum, plasma, or a concentrated "pellet" of *peripheral blood mononuclear cells* (PBMCs). Such is also the case with subject data, which are clearly not the totality of the person or any aspect of them, but which can allow new procedures and analysis, such as longitudinal aggregation to generate a view on an individual's life course, and combined with other people's data can produce "a population."

As Latour tells us, in demography the statistician loses the crying baby but gains a nativity rate (Latour 1987, 234). Data, unlike people, afford these aggregations to produce longitudinal, comparative views. Contrary to any naïve reductionist formulation, in which less and less will explain more and more of the world, what I have found in any ongoing collection endeavor is a proliferation of materials and data in all fields, each entangled with their own specializations, methods, apparatuses, and instruments.

While data or specimens are not reductions of the world on their own, in combinations of instruments, arguments, procedures, and visualizations, they are used to stand in for the world on many occasions. A sample of river water from May 5, 1995, "is from" the river at that time, the accompanying data "are" its salinity, temperature, and nitrogen levels on that day (with a reminder of the caveat above, that such properties are negotiated, rather than essential). And so, in addition to the data and specimens, we will also find a battery of work and materials dedicated to sustaining the relation of reference between data, specimens, and the river they came from. In inspecting the activities that seek to sustain a relation between data, specimens, and where they came from, we will find a further explosion of materials and artifacts: the sterilized vials for storing water and blood, the labels that mark their accession, the forms that are used to record data, the reference thermometer that is used to calibrate the one used in the field or the clinic. All of these are needed to ensure that scientists can continue to say that these data can stand in for this river at a particular point in time.

Trick of the Trade III: Seek Out New and More Materials, and Track the Work of Sustaining Ties of Reference (and Reduction) across Them

Overall, in the study of materials, an approach informed by irreducibility leads one to attend to the generation of new and more materials rather than the elimination of the world by the substitution of complex entities by simpler or fundamental ones.

A dangerous thread of recent materialist thinking has taken as its task to promote particular reductionisms, often casting all activity, things, and objects as fundamentally material. For instance, in an otherwise well-researched and argued investigation of bits, Jean-François Blanchette seems resolutely set on the task of displaying forever more material foundations to computation, asserting "if bits are not made from atoms, then what?" (Blanchette 2011). This approach, more theoretical assertion than methodological approach, takes the materialist argument one step too far, shifting from a practical investigation to an ontological assertion, inevitably leading us back to many old and polarizing problems that may culminate in discussions about whether there is such a thing as the experience of being a bat (Nagel 1974).

I find this tendency troubling for many reasons, but I will focus on the methodological difficulties that emerge: By espousing a particular material reductionism (data are fundamentally ordered atoms), the investigator may be blocked from an empirical investigation of the actors' epistemologies and ontologies, or more specifically, their relevant form of reduction. In calling data ordered atoms, what has occurred is an adoption of a particular reductionism, in the case, the reductionism of electrical engineering. That reductionism is real, instituted in innumerable texts and technologies; however, it is not the reductionism of ecologists and biomedical researchers. In studying their data practices, I have never seen them enact data as reducible to arranged atoms. They may very well think this is the case, but it is not enacted in their practice, nor particularly important for it. Instead, the important reductions are those of, in this case, ecological and biomedical science: in that field a thermometer reading from a river or a body "is" (and then immediately "was") its temperature, thereafter recorded *as data*. As a cool river or warm body is reduced to its temperature, we can observe the generation of something new: data. After this process we have a (presumably) differently cool river or warm body, along with a new thing, data, that these scientists seek to keep "the same" across all its future trajectories. Atoms and molecules may still play a role, such as for stream chemists interested in phosphorous content. Here the river is reduced to its chemical contents as new data are generated, but certainly no ecologist is thereafter reducing that data to the ordered atoms of electrical engineering.

The important practices that sustain these reductions for ecologists include calibration of their instruments, or careful body positionings relative to the river (see above). Sustaining ties of reference (e.g., this sample is from *this* river) and crafting compelling reductions (e.g., these data *are* the river's temperature) can be inspected as the practical work and technical armature of domains, disciplines, or actors. In doing so, the social analyst need neither commit nor oppose the links of reference or reductions.

Instead of reinterpreting the world as one set of fundamental materials, a material methodology gives the tools to recognize the situated and specifically textured nature of reductions and generations, as well as the importance of material agencies when they are encountered. In this sense, rather than casting materiality as an ontological assertion to be enacted across the board, materiality is an additional sensitizing concept along with those that draw our attention to the processuality of, say, practice, documents and archives, collaboration, power, and so on.

Historicist Materiality

The final trick of the trade is drawn from the nuanced empiricism of historical epistemology and ontology. Michel Foucault, who innovated the term "historical ontology" (more commonly known as the genealogical method), sought to examine the historical conditions of possibility for researchers to take interest in a "thing." In an example quite relevant to the case of the MACS, Foucault unearthed the conditions of possibility that paved way for doctors, psychologists, sociologists, and others in the 18th and 19th centuries to become interested in, and, more importantly, concerned with, the health of the population. Sex, or rather the regulation of sexual acts, came to be a central concern in the 19th century when the reproduction of the population became synonymous with a healthy economic and political environment; "There emerged the analysis of modes of sexual conduct, their determinations and their effects, at the boundary line of the biological and economic domains" (Foucault 1990, 26). Over time, such new objects of investigation were materialized by instrumentation that, for example, tracked the number of sexual partners or the tumescence of the penis (Waidzunas and Epstein 2015).

The work of historical epistemologists such as Lorraine Daston has additionally drawn our attention to the ways in which objects exit the repertoire of reality (2000). Things do not simply become objects of scientific concern and are thereafter explored "linearly," forever becoming better understood. Rather, the interest of scientists in certain objects can repeatedly wax and wane, and they can also cease to be of interest to science altogether. Thus, for Daston and others exploring historical epistemology, the focus is not only the things in themselves but also their social life within the sciences, and then without. A favored example in STS has been "phlogiston" (White 1932), a substance that for a time organized the attention of scientists interested in combustion before eventually falling out altogether from the pantheon of reality.

Rheinberger's work has emphasized the emergent or unfolding role of materials as sources of surprise, recalcitrance, and recurrence. He tracks a circuitous role for materials in his investigation of "cytoplasmic particles" as they were, first, epistemic objects of scientific investigation, but later those same entities became the tools or instruments for further investigations (Rheinberger 2000). It is common for scientific materials to play both roles in parallel, as with the case below where the Epstein Bar virus is used as the tool for immortalizing the cell lines even as that virus also remains the object of research for other scientists who continue to investigate its genetics, prevalence, transmission, and so on.

Example: Immobilized Data and Replicating Materials

A received view of data, as with any form of information, is that it can be copied indefinitely, while the correlate view of specimens is that they are finite. This is largely how they are treated in the MACS, resulting in different *regimes of valuation* for both (Dussauge et al. 2015). In the MACS, the demographic, behavioral, or medical data that have been generated about the participants have been reused hundreds, perhaps thousands of times in studies of many kinds. No matter how many times the data are used, they can still can be repurposed once again (as we saw above with the case of stream temperature data in LTER). In contrast, the specimens of blood are each unique and finite, with only a certain quantity collected and preserved from each man at each time point. To maximize their usage, the six vials that are collected at each visit are pipetted (or "alliquotted") into dozens of smaller vials before being placed in cold storage. Each aliquot can be defrosted, used in part, and the remaining materials frozen again—detailed instructions accompany each specimen to ensure investigators use only what they need and then properly return whatever is left over to the archive. Despite such care, ultimately, each use depletes the vial, and eventually for a given sliver of time there will be none left. And so, differently than data, the use of blood specimens is carefully deliberated, that is, weighing the prospective value of a particular study against the quantity of stored blood that will be used. Proposals for a study are occasionally rejected on this basis.

But there are circumstances where these received truths do not hold: data are not all organized to encourage sharing and replication, and materials need not always be finite. Unlike the demographic, behavioral, or biomedical data, personally identifying data that are held about the MACS participants, whether HIV positive or negative, are never shared. These data are kept separate from the rest (under "lock and key" for the first decades of the project, and now "behind password and encryption") and only a select group of staff and investigators have access to the men's real names, addresses, and contact information. In principle these data can be copied indefinitely, never depleting their archives, but in practice the MACS has evolved a complex privacy regime to ensure this is never the case. They do so at some expense, developing systems that keep personally identifying information in secured sites, and at a cost to their scientific enterprise (i.e., imagine the wealth of research that could be conducted if their vast troves of behavioral data could be linked to social media traces). Treated as data, identifying information can be copied and shared. But, inspected in relation to the sociotechnical system that sustains them, these data are best understood as part of an operation dedicated to ensuring they do not travel. However, a change in that privacy regime, or the more general subjects' protection guidelines and laws established in the United States, could change how those data circulate. Approached as a matter of the sociotechnical system that sustains privacy (or not), at this time these data have legal, technical, and practical protections that prevent the kind of indefinite copying we usually associate with data. The replicability and mobility of data should be approached not as inherent technical properties but as sociotechnical ones that shift at the intersection of technical capacities, guidelines, and laws.

Similarly, while in general we can say the blood archive is depleted by every use, there are circumstances when this is not the case. For instance, in 1997 MACS scientists isolated white blood cells from the specimens of over 1,900 participants and "immortalized" them through a technique that involves infecting them with Epstein-Barr virus. Thereafter these lymphoblastoid cell lines would reproduce indefinitely, providing a potentially infinite source of "the same" genetic material, a permanent resource for the studies that rely on these materials: "As these samples are used for a wide range of studies and will become limited as more studies related to human disease are performed, the establishment of cell lines as permanent resources of genomic DNA is considered a potential solution" (Herbeck et al. 2009). Again, the properties of these materials—blood, DNA, PBMCs—are not fixed, they operate in their own shifting regimes.

Trick of the Trade IV: Approach Materials Historically: They May Come, Go, or Change

A received understanding of data is that they can be copied indefinitely, whereas material specimens are finite, but inspected more specifically, and placed in relation to their use and stewarding, certain data inhabit complex sociotechnical architectures that are intended to prevent their copying, reuse, or circulation, and certain materials can be copied, or made to copy themselves, indefinitely. In the abstract, data are an infinite resource while specimens are scarce, but inspected historically, and in relation to the techniques and systems they inhabit, at times they display completely different properties.

We must "discover" the agencies and roles of materials in situ, and track their evolution empirically. The procedures for immortalizing cell lines have evolved in biology over the past century. The first immortal cell lines, such as the infamous HeLA (Landecker 2007), were developed almost serendipitously, but today novel techniques allow for the systematic creation of specific cell lines. Thus, across time, the technical capacities of biomedical research have shifted, and so too have the agencies of certain key biological materials—now "immortal."

The specimens of the MACS archive were once depleted by each use—and this is still the case with most materials. But for some very specific materials, it is now possible to "clone," "replicate," "amplify," or "immortalize" them through various techniques. Coupled with those innovations, we find a complex *regime of similarity and difference* that has emerged for lymphoblastoid cell lines that both enables and constrains their use as resources that treated them "as if" they were the same as the original specimens. Today, immortalized lymphoblastoid cell lines operate in a regime of care to avoid significant genetic drift relative to the originals, and even with the best methods, the process of their generation may lead to genotypic discrepancies. Thus, by treating materials historically, we must also return to the additional tricks of the trade discussed above: the regimes of similarity and difference that constrain and limit the use of these materials for generalizable research, or the local and relational enactment of materials. This form of analysis demands an astute and unrelenting historicism from the scholar of materiality: a material can never be treated as investigated, understood, and thereafter blackboxed; rather, it must be resituated historically and practically at each turn.

Overall, placing materials in changing historical and practical circumstances affords an understanding of their plastic and situated roles. Materials may come and go: sometimes in the sense of break-down (as with a gear), wearing away (like a pebble on a beach), or wearing down (like cartilage); but sometimes in the sense that they are no longer considered materials at all, as with phlogiston, a kind of dematerialization that retrospectively rewrites history. Even the most mundane materials can be an emergent source of deep and challenging complexity: so while "mud" has not been an exemplary object for the scientists most revered in history, it is an ongoing research challenge for the civil or automotive engineer (Hacking 1995).

Materiality as One Sensitizing Concept

I have presented four tricks of the trade out of a vast and diverse repertoire that is available to us for the inspection of materials, objects, and things in the STS tradition and beyond. I have not attempted a theoretical synthesis nor recounted a methodological progression. While the tricks appear in this chapter in a roughly chronological order to their association with methodological schools, it is not that the "newer tricks" have superseded the older ones—I continue to draw on all. So too is the case for tricks of the trade that preceded the materialist turn; for here I am advocating for adding tools to our repertoire rather than a revocation of what came before.

A story to exemplify this: In my recent move from Washington, DC to Seattle, I packed up my belongings and my dog Beemo for the final flight. Airlines are particular about how pets travel in their cargo holds and their well-documented guidelines are available online: for example, the transport crate should be made of hard plastic and held together with four metal screws, vaccinations should be current, and the pet should be checked in at least one hour before the flight. I fastidiously followed the extensive rules. But when I arrived at the airport, well early of the flight and with certificates in hand, one single missing screw almost derailed the entire move to Seattle. Somehow, one of the four required bolts that secured the crate had gone missing. The airline attendant told us in no uncertain terms that Beemo could not fly without. My meticulous planning for this move, otherwise smooth as butter, was derailed by a single absent bolt.

Is this case best analyzed in terms of its materiality—that is, of a missing bolt? In this case I tend to think not. Understanding this circumstance would be better served by approaching it in a more (sociologically) conventional matter of organizations and institutions. Beemo could not travel because she was not in line with the rules the airline had set forth for pet travel. Of course, in some extreme cases, that missing bolt could save her life. But that was not what was occurring: what was interrupting Beemo's flight was the enactment of an accountable checklist procedurally tied to pet travel.

What followed corroborates an organizational explanation: the missing bolt sent me, and some airline staff, into a frantic search for a screw that would fit the crate. After failing to find such a fastener, and after much pleading, the original airline attendant called her supervisor, who made a one-time exception to the rule. As with most institutional rule following, the encounter was morally charged: the supervisor did her due diligence by chiding me for my negligence. But Beemo made it on to the flight and off to Seattle we went. This work-around is also best understood institutionally—as a well-executed appeal to authority and situated decision making within an enacted organizational hierarchy. The absence of the fourth bolt played a role in this entire event, not in the material sense conveyed by Latour's speed bump that physically slows a car (Latour 1995), but rather in its more symbolic sense imparted within an institutional ecology.

Making sense of this circumstance as I have done here could be done with the tools supplied by Max Weber over a century ago. Despite the novelty of planes, rules posted online, computer-based checklists, plastic crates, and the luxury of flying dogs, this little vignette is best understood as a matter of organizational hierarchies, accountability, rule following, work-arounds, and other tricks of the trade that follow from the Weberian tradition of organizational analysis.

A materialist approach should not be dogma—a drive for a materialist purity—rather it is a sensitizing tool of the analyst, allowing us to hone in and make sense of the central aspects of the study at hand.

We cannot say anything about materiality in the abstract. Or more precisely, we can't say anything *interesting* about materiality in the abstract. Instead, it is best to say something about how to study materiality, how to make it something available for the inspection of its social, sociotechnical, or phenomenotechnical investigation. A common starting point for analysis of materiality is that past social theory and methodology has elided the material, and consequently has provided few analytic resources to make sense of it. In this respect, the turn to material analyses is a potentially revolutionary addition to our repertoire of study methods. But foreclosing the discussion with declarations about the nature of that materiality is foolhardy. Rather, materiality is our ongoing object of analysis within the manifold phenomena that are of interest to us.

My core point to the scholar interested in studying materiality is that if you really think materiality matters, then stay away from analyzing it in the abstract. If you believe "materiality" is a foundational reorientation of social research—and not simply an intellectual fad—then what we must do is develop the program by extending our ability to investigate materiality adeptly and to recount our findings meaningfully as we broaden our studies to more and more subjects.

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