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Tracing Data Flows in Norway and Austria: A Comparative Study of Vaccination Data Governance

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Abstract

The increased importance of datafication in different domains of society, and health in particular, has generated much attention in STS, specifically in the Nordic context. While much of this literature tackles newly emerging forms of data governance, we focus on a historically established and mundane data practice: that of recording vaccinations in vaccine registries. We mobilise the concept of data flows to compare the link between registry practices and governance in two countries: Norway – a data intensive welfare state - and Austria, which we label 'data hesitant'. We ask: What is the role of registries in vaccination governance? How do data practices shape and reflect relations between citizens, health providers and the state? We show that the governance of immunity is interlocked with the material and political circumstances that make data flow. The paper makes visible the benefits of doing situated comparisons for better understandings of data practices across countries.

Keywords: Registries, Vaccination Governance, Data Flows, Norway, Austria

Introduction

The COVID-19 pandemic revealed the immediate relevance of immunisation data for vaccination governance. For many national immunisation programs, data registry practices appeared insufficient for providing an accurate account of vaccine coverage or target risk groups, and to make prioritizations as to who should be vaccinated and when. One example is Austria, where in January 2022, the parliament passed a new law by which COVID-19 vaccination became mandatory for residents above the age of 18 (with several exemptions). Yet amongst other things, it was unclear how those who had not been vaccinated could be identified and how compliance with the vaccine mandate could be monitored. It appeared impossible to link the newly established vaccine registry with the existing population registry and the epidemiological registry (which records people who tested positive for COVID-19). In other words, it appeared technically and politically impossible to move data from one registry to another, to enable the correct data to flow to the proper sites, and to enforce a historic piece of legislation – which was then ultimately abolished.

This is but one example of how immunisation registry data can play a central role in governing vaccination not only in times of crisis, but also in 'normal' times. As epidemiologists have shown (see, for instance, Crowcroft and Levy-Bruhl, 2017), registry practices vary considerably across countries, including the technical arrangements, actors, and practices that are involved in making data flow and that make it interoperable with other data. From the perspective of science and technology studies (STS), this variability in data practices and infrastructures is not surprising, of course, but their link to contemporary forms of governance remains insufficiently explored. Doing comparisons between specific practices of governing health and disease across countries seems particularly pressing in the context of the ongoing pandemic, where the efficiency and reliability of immunization registries and the (lack of) interoperability of registry data have shaped not only public debates but vaccination governance itself. This paper examines this link and asks: What is the role of registries in vaccination governance? How do data practices shape and reflect relations between citizens, health providers and the state? In this paper, we study different versions of immunisation registries in two countries: Norway – a paradigmatic data intensive welfare state - and Austria, which we label 'data hesitant'. We analyse how both countries have developed and implemented different registry infrastructures for collecting data on vaccination. Our analysis focusses on childhood immunisation programs which are central pillars of public health governance in welfare states, where political, historical, and cultural differences are particularly prevalent. While childhood immunisation programs constitute our focus, out of necessity, our analysis also sheds light on how registries re-emerged as a governance issue in Norway and Austria in the early COVID-19 pandemic.

The main analytical concept that we mobilise in this study to capture and understand differences in immunisation (data) governance is 'data flows'. Building upon a rapidly emerging body of studies on data practices and data journeys in STS (see for example Leonelli and Tempini, 2020; Bates et al., 2016) allows us to examine the material, social and political circumstances that make data travel and the values, agencies, and responsibilities that are tied to and negotiated on these journeys. We postulate that data practices shape and reflect deep-rooted historical and political differences in governance. Our comparative approach foregrounds, first, how the achievement of individual and collective immunity is intimately linked to the material and political conditions that make data flow (or not). Second, and relatedly, we show how data flows, in turn, make available specific ways in which state authorities, citizens, and health care providers become tied together. Below, we lay out the analytical framework of our study and then proceed to explain our methodological approach. Subsequently, our empirical analysis provides a detailed account of (vaccination) data governance in Norway and Austria and the kind of relations they entail between the state, health providers, and citizens.

Investigating registry practices and data flows

Scholarship on datafication and digitalisation has commented critically on the varied impact of the arrival of big data with respect to its potential to not only increase surveillance (Boyd and Crawford, 2012), but also its capacity to produce data for curing diseases or enhancing access to information. Overall, the 'datafication of health' (Ruckenstein and Dow Schüll, 2017) and medicine has been of key interest among the emerging body of studies in STS, and much has been written on how databases and new digital tools redistribute and challenge ethics, accountability, transparency, citizenship, as well as patienthood (e.g., Hoyer et al., 2019; Pinel and Svendsen, 2021; Ruppert et al., 2017; Cakici et al., 2019). The growing number of studies focussing on the intense datafication and data optimism in the Nordic countries is particularly noteworthy (Bauer, 2014) but tends to privilege data-intensive forms of governance over those that feature a reluctance or hesitancy towards datafication and digitalisation (Paul and Haddad, 2019; Paul and Loer, 2019). The present study seeks to contribute to our understanding of datafication and digitalisation by contrasting two paradigmatic instances that are situated at opposite ends of a spectrum of datafication: Norway presents a case of data-intensive governance while Austria features what one may call data hesitant governance. Setting these against one another is instructive for understanding the link between registry practices and governance more fundamentally in and beyond the public health domain. Our study of data flows in vaccination governance also speaks to the longstanding interest in enumerative practices for government and state formations (e.g., Porter, 1995; Desrosières, 1998; Scott, 1998). Building on these earlier studies of data practices, more recent work has turned to the socio-material conditions for collecting, sharing, and using digital data beyond the state, including scientific research and industry actors (e.g., Leonelli 2020) and the values, frictions, or challenges in accountability that emerge from new data (Pinel and Svendsen, 2021; Leonelli and Tempini, 2020; Amelang and Bauer, 2019; Høyer et al., 2019; Høyer, 2019; Bates et al., 2016; Tupasela et al., 2020). Overall, it becomes clear that registries do not merely consist of devices and their technical connections, but function to tie together, or hold apart, a range of actors, practices, values, and imaginaries (Star and Ruhleder, 1996).

In the recent edited volume on *Data Journeys in the Sciences* (Leonelli and Tempini, 2020), Leonelli proposes the concept of 'data journeys' to capture and analyse the different "conditions under which data are handled, understanding the reasons underpinning such diversity, and identifying nodes of difference and similarity in ways that can help develop best practice" (Leonelli, 2020: 5). Like Leonelli, Bates et al. (2016) point to the 'frictions' of data journeys and how these are linked to the historical, cultural, and political circumstances of the data. Others have mobilised the concept of *data flows* to analyse the various attachments that enable and emerge from such journeys. The work of Høyer et al. (2017) and Pinel and Svendsen (2021) on flows, nonflows, and overflow, for instance, points to the need to study the role of data flows for enabling particular relations between individuals and the state.

The present study pushes this link between data flows and governance forward. We do so by focusing on an area of datafication that has typically gone unnoticed in the literature on enumerative practices, perhaps due to its seemingly mundane character: that of immunisation registries. Most scholarship on immunisation data practices and governance has focussed on technical aspects and challenges related to the collection, use, and sharing of data (e.g., Pebody, 2012; Balog, 2012), leaving the political aspects of these questions unattended to. Yet, vaccine registries are clearly political in nature: First, they contain decisions as to how individuals and populations are targeted and what interventions are included as data points (i.e., childhood vaccines, COVID booster vaccines, etc). Second, the design and use of registries involve questions as to how this data can or should be used, such as for monitoring individual and collective immunity, or vaccine uptake among specific groups. Third, registries imply decisions as by whom this data can be used and thus distribute agency and responsibilities differently. The concept of data flows helps us to tease out these political aspects and to understand how data comes to matter in the first place. It further helps us locate data in a concrete physical space – such as doctor's offices or electronic vaccination records - and importantly, highlights 'frictions' of data flows and how these generate and reflect particular forms of vaccination governance. Moreover, this conceptualization emphasizes how differences and contingencies make available different ways in which state authorities, citizens, and health care providers become tied together by vaccine registries – and thus shape what it means to be a citizen not only through data (Friese and Latimer, 2019; Ruppert et al., 2017; Cakici et al., 2019) but through the practices and infrastructures that make data flow (or not). Finally, paying attention to 'flows' provides a framework and approach to do comparison in a manner that is sensitive to contextually contingent practices of governance.

Methods and materials: Doing comparative case studies of data flows

In the volume *Thickening Comparison: On Multiple Facets of Comparability*, Niewöhner and Scheffer (2010: 3) make a case for comparison in ethnographic research that should "(exceed) both the single case study and the contrasting of any number of multiple cases". Drawing on Geertz's (1973) notion of 'thick description', Niewöhner and Scheffer (2010) argue that thickness emerges in and from comparison for two reasons: first, because it requires a processual and explorative attentiveness to the objects and what is compared; and second, it calls for an awareness of the limitations of doing comparisons and the reductions it might implicate (Niewöhner and Scheffer, 2010: 3–4; see also Friese and Latimer, 2019; Deville et al., 2016). This argument is in line with other methodological contributions in STS that engage affirmatively with comparisons and the field's emphasis on case studies as a methodological and analytical critique of universals (Beaulieu et al., 2007). Like Niewöhner and Scheffer, Beaulieu and colleagues (2007: 687) point out how doing comparative studies relies upon careful staging of the research object – "not through the use of a formalized framework, but through interaction and conversation".

The idea for this paper emerges from a shared interest among the authors in challenges related to governing immunization, as well as a long-standing interest in the politics of health and disease (Bjørkdahl and Druglitrø 2019; Paul 2016; Paul and Loer, 2019). The immediate differences that seemed to exist in our empirical sites (Norway and Austria) regarding registry practices stood in stark contrast to the ongoing requirements for interoperability of immunisation data at the European level and the level of the World Health Organisation (Pichelstorfer and Paul, 2022). These efforts to establish technical interoperability appeared to be a means towards joint action where political integration – a joint vaccination program - remains impossible. Observing these tensions between technical and political integration in our respective national contexts in more detail, our objects of comparison became shaped through what Niewöhner and Scheffer (2010) have called 'thickening contextualisations'. The thickening was achieved by different methodological strategies for the two sites: we conducted a mainly document-based analysis and web-based study to examine Norwegian data flows, supplemented with two interviews. Our study of Austrian data flows was primarily shaped by interviews, supplemented with document analysis. We will detail these asymmetries in data collection in the following sections. The differences in our methodological approaches reflect the material differences in data flows in our two cases, including where and by and for whom the data is made accessible.

The Norwegian system for data registry practice features – at least at the level of policy reports, scholarly literature, and web portals – a high degree of transparency and accessibility. The web portal of the Norwegian National Institute of Public Health (NIPH) is, for instance, comprehensive in terms of statistics, reports, publications, legal texts, and fact sheets, providing a rich empirical field site. The website became an important site for accessing reports and newsletters about immunisation data. Another web portal that has been important for this analysis is "Helsenorge.no" and "My Vaccines", where individual citizens have direct access to their personal immunisation information. The relevant regulations around immunisation and health data, including data protection, are also all accessible online. We have particularly investigated the Norwegian Immunization Directive (SYSVAK), which is the key legal text for governing the administration of vaccination and immunisation data, and the Health Registries Act [Helseregisterloven] that manages data protection concerns of registry data and the Infection Protection Act [Smittevernloven]. We also accessed online newspaper articles, press releases by the Ministry of Health, and other published interviews with stakeholders about the infrastructures for making immunisation data flow in the Norwegian context. We additionally interviewed two experts (in Norwegian) at the Infectious Disease Registries located at the NIPH who were responsible for immunisation data collection, sharing, and use. These interviews (including follow-up questions and clarifications via subsequent email exchange) were mainly to clarify aspects of our analysis of online sources.

In Austria, in contrast to the remarkable transparency and accessibility in Norway, documentation of the National Immunisation Program (NIP) has largely been limited to publications of annual vaccination rates that are aggregated on a national level, which conceal regional variations and fractured forms of health data governance. Moreover, the closed-off nature of policymaking (Prainsack and Gmeiner, 2008) restricts the accessibility of policy materials for researchers – hence raising a need for interviews. To be clear, while access to digital documents (e.g., annual reports and vaccination schedules) is common, these documents remain fairly technocratic and do not offer insight into policy practices and implementation. What is more, at the level of federal states, even digital material is scarce and much knowledge is shared informally. The purpose of the interviews was to understand not only different perspectives, but specific practices. In this sense, we conducted them with a certain "ethnographic sensibility" (Prainsack and Wahlberg, 2013) where in-person interviews enabled access to data flow materials that would have otherwise remained inaccessible. As for the Austrian case, we draw on ten interviews (in German) with policy officials and epidemiologists at public health authorities involved in collecting, curating, and using childhood immunisation data. These practice-oriented interviews were specifically conducted for a study of vaccination registries in 2018 using a semi-structured interview guide that aimed at eliciting narratives about data *practices*, and more specifically how data infrastructures were set up and how data is collected, shared, and used. We approached senior officials and program managers in four out of nine federal states. In our sampling strategy, we aimed for variation in our selection of sites to understand the variability of data collection in Austria. Document analysis included annual reports by the Ministry of Health over the period of five years, the mother child health pass, the websites of pertinent authorities (Ministry of Health, social insurers) and printed material provided by state authorities. Some of this material was not publicly accessible but was collected during the interviews when interview partners demonstrated how they produced and shared data on immunisation, using artefacts such as vouchers and template letters or pointing out features of software in use.

Using these materials, we sought to trace the infrastructures of data flows and in what form data travels, and what actors and networks are put to work in making data flow. We also focus on how vaccination registries are mobilised as governance tools in policy reports, and on the material set-up of the two national immunisation programs, i.e., the infrastructures in which vaccines are administered and recorded, exploring what is recorded or not, by whom, and to what end. In our analysis, we use five joint themes to organize the material: data entry (with locations and involved actors); material data infrastructures and their historical development; data sharing and data frictions (i.e. references to disconnections and disruptions of data flows); data use (e.g. for public health monitoring); and the role ascribed to different actors (e.g., public health institutions, epidemiologists, doctors, citizens) in registries (e.g. as producers, owners, or users of data). While comparative analysis risks losing empirical, normative, or conceptual detail that emerges in single case studies, it has clear benefits by putting insights from single case studies into perspective and specifically allowed us to pool knowledge from two parallel research projects. Our own entanglement in the two policy contexts as well as our experiential knowledge both as users of and commentators on these two systems proved useful in obtaining access to the field. This ethnographic sensibility (Prainsack and Wahlberg, 2013) along with our experience of the pandemic shaped our comparative approach and the multiple iterations of our analysis. The following section, we begin our analysis by exploring the contingencies of organising, regulating, and valuing immunisation data and registries, and how they have developed over time. We trace how immunisation data is put to work in different ways in two national immunisation programs – that of Austria and Norway – and networks of sites and stakeholders that are included in the organisation of immunisation governance. Subsequently, we focus more intimately on how data flows, what and whose work is involved in making data flow across different locations and how these flows mirror and reproduce particular relations between the state, citizens, and healthcare providers.

Tracing public health (data) practices and data flows

Norway: data flow optimism and tight couplings

Scholarly literature on Nordic countries suggest that the establishment of data registries was closely connected with the establishment of a welfare state, and the flow of data to registries and between different registries are said to have shaped how individual citizens could be governed (Alastalo and Helen, 2021; see also Bauer, 2014; Eklöf, 2016; Schiøtz, 2003; Alver et al., 2013; Thygesen et al., 2011; Lie and Roll-Hansen, 2001). Parallel to this data intensive governance and 'data optimism' (Lie and Roll-Hansen, 2001), Norway is usually said to feature a high acceptance of centralized and interventionist public health policy (Tupasela et al., 2020). Immunisation strategies have largely been politically uncontroversial and immunisation rates have been traditionally high (Asdal and Gradmann, 2014: 182)[1]. There is an advanced legal apparatus around health registries that condition the work of health care providers, including the EU General Data Protection Regulation (GDPR), which was implemented in Norway in 2018. The National Immunization Directive (SYSVAK-Directive) provides the foundation for this centralised structure. The Norwegian Immunisation Registry called SYSVAK was first introduced in the 1970s and is said to be the state's most comprehensive preventative measure oriented towards individual citizens (Alver et al., 2013). The aim of the SYSVAK registry was to get a comprehensive overview of vaccination coverage at national, county, and municipal levels, and importantly an overview of the impact of the Childhood Immunisation Program (CIP). As officials at the Infectious Disease Registries office pointed out in our interview: "The Child Immunisation Program has always been the most important part of SYSVAK" (Interview 11). Another important aim they emphasised was to ensure that this registry, combined with other registries, could provide a foundation for different health statistics and for research. For example, data from SYSVAK are made available for researchers, a process that is shaped by a set of procedures and legal regulations and requirements for use.

Norway has fifteen national health registries, including SYSVAK. The SYSVAK registry is linked to an electronic patient record system, a system where health providers register immunisation data (a system we will return below). The public health system around immunisation is closely integrated with the flow of data into SYSVAK. New parents, specifically mothers, are immediately enrolled in the healthcare system based on their personal identification number and their assignment to a public nurse at a local health station. Here, parents of infants receive standardised instructions related to postnatal care of child and maternal health. It is also in this space that children are enrolled in the child immunisation program, which is structured as a call-recall system until the age of fifteen. This system features a logic of equal access to vaccinations for all children regardless of their social status. While vaccination is not mandatory in Norway, to abstain from participating in the program involves active resistance from parents. Local health stations administer the call-recall system, and with the help of these datafied infrastructures, public health nurses, located at schools, help sustain immunisation as the default choice. These standardised arrangements to health care may be an important reason for why hesitancy around the vaccines in the national immunisation program is less prevalent in Norway, than in, for instance, Austria. The infrastructure for childhood immunisation suggests a strong social norm, that of participating in not only a highly datafied public health infrastructure, but the joint production of collective immunity.

In our interviews, officials at the Infectious Disease Registries (which administers the SYSVAK registry) highlighted the close link between registering data correctly and conscientiously, the value of 'good registry data', and individual health (Interview 11). They emphasised how the SYSVAK regulations delegate a lot of responsibility to health care professionals. When performing vaccinations, health care workers in Norway are obliged to 'register and report correct vaccination information to SYSVAK' (NIPH, 2014). This obligation is established in the SYSVAK Directive (*Forskrift om innsamling og behandling av helseopplysninger i Nasjonalt vaksinasjonsregister (SYSVAK-registerforskriften*) mentioned above. The directive requires that the authorised health provider has access to an electronic patient record system (EPR) with 'SYSVAK integration and communication'. Most health providers have an EPR system with a SYSVAK integration, but the pandemic also made visible how many health care locations where vaccinations usually would not be conducted, such as elderly health care centres, also needed to be equipped with this system in order to participate in the national corona vaccination program. "It is a well-established system, and we have health personnel that is good and conscientious. (…) So, our health personnel believe in the significance of [collecting data] as well as their duties and part in it." (Interview 11).

When the public health nurse registers the vaccine, the person and vaccine are linked to the *personal identification number* of the person receiving it. From SYSVAK, the aggregated data will flow 'back to' the public in different shapes – in statistics at the national, municipal, and individual level (including through digital platforms where citizens can access personal health data by using their personal identification numbers and the BankID service, as we will discuss later). While the data that flows into SYSVAK specifically is identifiable at the individual level, only a certain number of persons at the NIPH are authorised to couple immunisation data with personal identification numbers. Here, data protection regulations play a key role. In reports on vaccine coverage directed towards the public, the data will be available at the county and national level. Data at the municipality level can be accessed through the Statistical Bank of Municipality Health '(*Kommunehelsas statistikkbank*)'.

A characteristic feature of Norwegian immunisation governance is then that data is valued as a source for knowledge production that can provide the foundation for immunisation control and surveillance and be used for developing new research-based public health policy strategies. Another characteristic is how legal structures and a clear demarcation of expertise and responsibility make sure that data is collected and put to work in different sites and by different actors. 'Good' immunisation (data) governance in the Norwegian context depends upon the ability to legally tie together a broad set of actors, sites, and technical solutions to sustain a good data flow. For instance, the role of public officials in making data flow is directly linked to individual person's immunity, by their legally assigned responsibility to ensure the reliability of the data that is made to flow into the SYSVAK registry. When the data is reported to SYSVAK, it does not simply flow into the registry. It has to be validated first and this is done by manual as well as automated procedures, which sometimes fail and disrupt flow. In this part of the flow, the role of the officials is to take out 'instances' that they are sure are wrong.[2] This is what they call 'data washing (*datavask*)'. To do this they use a 'rule engine'. In our interview they described the rule engine in this way:

> You can say the rule engine washes in its own way, because it "throws out" people who apparently have not received all doses according to recommendations and programs from the statistics. But the purpose of it is actually to check if a person is completely protected against the given disease they are vaccinated against. The rule engine is easily set up. It runs through a series of rules per person per vaccine dose where it counts days between doses. (Interview 11)

In our interviews, the officials highlighted how frictions in this tightly coupled system would regularly occur – for instance, from typing errors from health personnel or technical errors in the system. "We spend a lot of time on technical error in vaccination reports," the public officials said. If error happens, it may, according to the officials, directly affect children's immunity: "If the wrong date is registered for example, it will affect the intervals of vaccination and the child's immunity – for example if the dose is given too early" (Interview 11). The direct link between registry data, data-based actions, and status of immunity was the subject of public debate during the COVID-19 pandemic. The NIPH launched the emergency preparedness registry named 'Beredt-C19' ('Prepared-C19') as an addition to the national immunisation program to "frequently extract and compile data from the various data sources" to provide the authorities with the "relevant, essential knowledge base to deal with the COVID-19 epidemic" (NIPH, 2020). Daily couplings were made between this registry and other registries, and correspondingly, the NIPH received daily inquiries by researchers requesting access to the registry data. This coupling of registries generated, for instance, the insight that occupational groups such as waiters and bus drivers are at a greater risk of COVID-19 infection (Magnusson et al., 2020). Furthermore, when Norwegian decision makers were discussing how they could improve vaccination rates, they could use an immunisation registry which was well linked with other registries.[3] The interoperability of different registries enabled health authorities in principle to identify individuals who, for example, had not been vaccinated.

However, during the COVID-19 pandemic, the unusual situation of having to reach and immunise a large proportion of the population within a relatively short time span revealed the shortcomings of registries (even though tightly coupled) to provide a basis for mass-immunisation and prioritizations in vaccination governance. For example, the phone registries (which again are linked up to the personal identification number of each citizen) were not reliable in that several phone numbers could be registered to one person, but used by others (for instance, family members). Furthermore, when it came to defining prioritization schemes for COVID-19 vaccination in late 2021, critical voices pointed out how exclusively identifying risk groups based upon registry data foreclosed discussion of other and more efficient ways of realising herd immunity (see, for instance, Mamelund et al., 2021).

Hence, frictions in data flows regularly come to the fore despite the tight couplings between registries, sites, and expertise through which data travels, and despite the rather comprehensive legal structures that shape this practice. These frictions might be due to technical errors in the reporting or curation of data or when the registry data provides the foundation for making prioritizations in terms of vaccination, as during the pandemic. How can these flows and frictions be compared to the Austrian situation?

Austria: data flow resistance and loose couplings

Austria is organised according to a federalist structure whereby public health policy, including implementation of vaccination policy, remains mainly within the remit of its nine federal states. The national childhood immunisation program in Austria was established in 1998, a few decades after its Norwegian counterpart SYSVAK was first piloted. Like in Norway, childhood vaccination in Austria remains voluntary, and the target group for the national immunisation program consists of children up to the age of 15 years. While the two cases both share this central value of promoting collective immunity, institutional design and implementation practices differ substantially across the two countries. Vaccination rates are comparatively low in Austria, according to the World Health Organization (WHO) (2020) – one in five infants do not receive basic vaccinations by the age of two. Public health infrastructures are less visible than in the Norwegian case as childhood vaccinations are typically administered in GP offices, rather than public vaccination centres, and childhood vaccination practices strongly rely on the initiatives of medical professionals, parents, and caregivers. New parents and their children are not automatically assigned to a public health institution but need to take initiative in finding a paediatrician to arrange for childhood immunisations.

In the same way as implementation of the national immunization program is shaped by the federalist setup, each federal state is responsible for gathering and reporting data about childhood vaccination to the Ministry of Health and has established particular practices and infrastructures for doing so. While epidemiologists, who assign great scientific value to immunisation data, have long called for a more centralized approach, Austria continued to lack one until the emergence of a rapidly designed registry for COVID-19 vaccines, as discussed further below. In fact, and in contrast to Norwegian practices, Austria has a history of *resisting* the centralization of data infrastructures and collection of public health data, stemming from conflicts over 'data ownership' between federal states, the Ministry of Health, general practitioners, and epidemiologists that view data as a public good.[4] Pointing to this controversy over data ownership, an epidemiologist argues: "this data does not belong to the Ministry of Health […] we collect and record this data as part of the national surveillance system and from the point of view on data protection it belongs to no one" (Interview 7). These concerns over data ownership and access to vaccination data in combination with the argument by the Austrian Medical Association that public health data collection might not be reconcilable with data protection effectively prevented the centralization of data infrastructures for years (Paul et al, 2021).[5] Notably, our interview partners referred to data protection as a central political value more generally, rather than specific regulations that may apply, such as the EU General Data Protection Regulation (GDPR) or the Austrian E-Health Regulation (*Gesundheitstelematikgesetz*).

As our interviews reveal, a diverse range of methods of collecting data on childhood immunisation are used across the country, shaping how data flows are organised and, by extension, what kind of knowledge can be produced about the immunity of the Austrian population. In contrast to Norway, the practice of immunising an individual is only loosely linked to the immunisation data used by the state.[6] This has several reasons: For one, instead of legally defined responsibilities to report data as in the Norwegian case, GPs and paediatricians in Austria are only paid for administering vaccines once their data is delivered on a quarterly basis, thus creating a financial incentive for data reporting. Private doctors, however, where patients pay out of pocket, typically have little incentive to submit data, as payments for data delivery are considered comparatively low. This leaves a substantial number of childhood (and other) vaccinations provided unaccounted for. Furthermore, immunisation data travels through many different sites. Once it is collected by doctors in private practices, it moves to local health offices, then onwards to the regional health directorate, who then report aggregate data to the Ministry of Health on a quarterly basis. Moreover, a variety of data collection practices exist in Austria: While in some states, paper vouchers are distributed to parents of infants and then collected at the point of care to document vaccination, other states rely on doctors to document vaccination themselves and to report these to local public health authorities. In addition, some states collect individual level data on vaccination, whereas others do not. Finally, as a public health official points out, such data work is onerous and risks distracting from what they understand to be their main responsibility: "our aim is to ensure that children are vaccinated, and we therefore sometimes forgo data collection" (Interview 8).

These different data registries (and some of our interview partners questioned whether the term registry is even applicable for some of the regional databases) are not used for research, nor can individual immunisation records be linked to population registries. Instead, these registries primarily serve to organize the reimbursement of primary care physicians and calculate an estimated vaccination coverage rate for a specific cohort. Respondents also critically comment on the way some data is merely stored, but not used: school-based data (such as on vaccination, but also screenings) is thought to "end up in some drawer" (Interview 1) and is not put to use for research purposes. A senior public health official, for instance, tells us she would like to measure the impact of regional information campaigns (Interview 3) to get a better understanding of the impact of their own work. An electronic vaccination pass, she suggests, would also help her get better resources, "for it would provide numbers which have more effect [to substantiate a claim for money for a new program]" (Interview 3).

In whichever way this data is collected at the decentralized level of federal states, individual level data, including all local knowledge this implies, is disembedded from the data files once this data is delivered to the Ministry of Health, which is done on a quarterly basis. This anonymised, aggregated dataset typically includes only vaccines per recent birth cohort rather than the complete dataset, thus, as statisticians and epidemiologists argue, adding to imprecision (Interview 9, 10). Due to the highly localised and different ways of counting, national vaccination rates can only be estimated. The fact that data is not effectively used for centralised steering or research does not mean that data is not valued as such, but that digitalisation in vaccination governance – and other policy areas, for that matter – presents something like a

Pandora's box to decision makers. Better data and more knowledge from secondary research risks revealing that tackling under-vaccination may require more complex, and more politically and financially costly interventions, such as addressing socio-economic inequalities or rethinking the voluntary and loosely organised nature of the national immunisation programme. In contrast to our Norwegian case, where independent research on public health and evaluations of its governance is enabled by access to registries, these questions remain unaddressed in Austria, for the very nature of infrastructures shapes what kind of evaluative questions can be asked to begin with.

Given that public health infrastructures in Austria are less centralized than in the Norwegian case, and that vaccinations are typically administered in paediatric or GP offices rather than at public vaccination centres, childhood vaccination strongly relies on the initiatives of medical professionals and parents (similar to adult vaccinations in Norway). In addition, the fact that childhood vaccines are mostly administered in doctors' private practices foregrounds individual decision-making rather than the communal value of vaccination. This loose link between individual immunisation and collective immunity is also reflected in the ways in which data loosely travels from the site of vaccine provision to administrative bodies and state authorities. There are thus many obstructions to data flow built into the Austrian immunisation data practices. They range from questions concerning the distributed authority to gather data, distributed ownership of data, material properties of the data (where the variety of data forms, ranging from paper-based records to excel spreadsheets or local digital systems, make it more difficult for data to travel), and historically established resistances to centralized data collection. This fragmentation stands in contrast to the value assigned to centralized health data in the case of the Norwegian data imaginary.

Data flows and the making (and remaking) of citizen-state relations

Norway: good vaccination governance as (digitized) user-participation

Making immunisation data available to the broader public is a key part of the SYSVAK's activities. On the SYSVAK websites of the NIPH, there are statistics on corona vaccination, child immunisation program, HPV vaccinations and the overall SYSVAK registry. The statistics are accompanied by explanatory text, and hyperlinks are used to link up to related, but specialised topics. A video is uploaded on the frontpage with the title: "How to register data in SYSVAK", clearly targeting health personnel. There is also information about the vaccination service and how it is linked up to the registry data, an overview of data protection, and rights related to accessing and deleting data. Individual citizens are more directly linked up to the data flow by other digital platforms and numerical tools. Recently, individuals have been attributed increased responsibility for personal immunisation data by the development of different digital solutions for making this data flow from the point of immunisation, through the registries, and back to the citizens. Since 2011, individual level data has flowed back to the individual citizen mainly through the digital service *Helsenorge.no*. At its launch, the reasoning given to the public was that disseminating immunisation information to citizens would provide "better care and better health services" (Strøm-Erichsen, 2011 cited in Bjerkestrand, 2016; see also NRK 2011, 15 June). The service was framed according to the principle of "user participation" (Norwegian: *brukermedvirkning*)[7], which meant that 'users' – or citizens – have control of the personal immunisation data that the state collects but also are envisioned to be able to better take care of themselves in terms of health. The Minister of Health and Social Affairs stated in their press release: "The health services must - to a greater extent than today - be able to involve users and patients. I mean that the patient must be enabled to be an active participant in questions regarding their own health. That means amongst other things that we need to focus strongly on digital services" (Strøm-Erichsen, 2011 cited in Bjerkestrand, 2016; see also NRK 2011, 15 June).

In the beginning, the web portal was packed with health information relating to different issues and problems, enacting the 'traditional' top-down mode of public health *communication*, but in a new outfit, so to speak (see Bjørkdahl and Druglitrø, 2019). Access to information about immunisation status and vaccines was added the same year as the launch under the heading 'My vaccines', making it possible also to download up-to-date vaccine passports. Since then, various adjustments have been made. For instance, 'My Vaccines' now also offers detailed information about past vaccinations, as well as a log showing by whom and when individual immunisation data has been accessed, and for what purposes.

This arrangement enacts the citizen as a co-owner of data and grants them a right to transparency in data flows. In 2021, Helsenorge.no was launched as a mobile app, providing personal health data directly to mobile phones. While the portal was from the outset promoted as adaptable and dynamic where new features could be added when needed, critics asked if this was only another addition to the state's 'collection of digital links' (Bjerkestrand, 2016) – not only pointing to the obsession of technical fixes to problems of public administration, but also a comment on the top-down and non-user-friendly mode of communicating health information. While the issue of data protection has accompanied different technical solutions in Norway, our study indicates that other problems and issues have also increasingly featured in public debates.

In the Norwegian case we see how data flows connect different locations and actors. This heterogeneity is enabled and sustained by the broad distribution of responsibility attached to the curators of data or the bearers of data: technical systems, health care providers, and citizens. There are no, at least in principle, passive producers or recipients of data. Public health infrastructures, and to a great extent public health policies, target the individual and facilitate the active participation of citizens in reaching the immunisation goals of the state. This also includes the broader 'publics': technologists and informaticians, public health officers, interest organisations, and others. At the same time, while data seems to flow quite smoothly across many sites, we have also begun to identify frictions in terms of what is experienced as good and bad modes of governing vaccination.

Austria: from local to centralised data flows and emerging 'users'

The Austrian data practices do not only differ from Norwegian ones in the extent of datafication and how this data is made to travel through different sites to the state, but also by whom this data can be used and for what purposes. Through the specific ways in which only some data is made to flow (individual level data is removed from the aggregated data file that is sent to the Ministry of Health), these data practices enact citizenship differently than in our Norwegian case: in Austria, the citizen is a resource for data, but data does not flow back to the citizen. While citizens have an active role in vaccination governance and are, together with health care providers, responsible for monitoring their immunisation status or that of their children without the interference of an active state (distinct from the Norwegian system, there is no call-recall system in place)[8], they are not involved in data management, curation, or use. More specifically, they are rendered absent as individuals as soon as data moves from regional public health offices to the Ministry of Health. As mentioned above, the data that is used at the national level constructs a collective based on aggregated data where all references to individuals have been removed. This absent individual must be understood against the backdrop of a strong concern in Austria for individual data protection and privacy through which all efforts to health data collection have been framed and, in many cases, have been successfully opposed.

Furthermore, beyond the specific COVID-19 registry, these locally specific vaccine registries cannot be linked to individual level data, such as in population registries, thus hindering more specific assessments of the vaccination system, of specific regions with a low vaccine uptake, or of subgroups that may be hard to reach or are otherwise vulnerable. Data frictions and the lack of interoperability with other registry systems, such as the population registry, influence who is or can be targeted and governed through immunisation data collection, curation, and use, in what ways, and whose immunity can become knowable and manageable.

The limited availability of immunisation data for governance changed substantially with the development of COVID-19 vaccines. The pandemic provided a window of opportunity for accelerating a long-standing techno-political project, the introduction of electronic vaccination cards and, underlying these, a central registry. New legislation on digital health was rapidly passed in October 2020, establishing a legal and at once moral mandate for individual-level data collection for the sake of public health (Gesundheitstelematikgesetz, 2020). The pandemic offered an opportunity to introduce the electronic vaccination card rapidly without extensive societal debate, and specifically without providing the legal possibility of opting out of data collection. This is particularly interesting given the historical resistance to digitalisation, specifically from medical associations, data protection activists, and local authorities that had invested in their own local data infrastructures – often citing economic costs as being in the way of centralisation. While the electronic vaccination card was initially planned for the national childhood immunisation program, its implementation was strongly shaped by the pandemic and currently includes only data on COVID-19 vaccines – not solving the data frictions teased out and discussed above. In the long term, the digital record is meant to achieve a variety of goals: to gradually replace paper-based vaccination records, to integrate federal data registries into a centralized vaccine registry, to increase administrative efficacy, and to enable better governance of communicable diseases, including the ability to assess and manage collective immunity. In addition, and crucially so, the electronic vaccination card is to allow citizens to access and download their own immunisation record. The download option also includes access to a personalised digital EU COVID-19 Certificate, or Green Pass. The electronic vaccination card functions as a technology that provides citizens with a different role in the practices of governing vaccination and immunological relations. It enables new data flows between different sites and actors (e.g., GP practices, public health centres, Ministry of Health, citizens), and these data flows have been further facilitated by a change in legislation which mandates health care providers to deliver data on COVID-19 vaccination data electronically – much like in the Norwegian case.

This additional data infrastructure produces a particular relation between citizens and the state: at least for the purpose of pandemic management, the state now obtains precise data on which segments of the population have (not) been vaccinated. In addition, it ties together vaccination and the use of data to participation in society: the vaccination became an entry requirement for many places such as restaurants, gyms, or hair stylists. The way in which data is made to flow makes citizens not only into objects of data (data is collected about them) but also into subjects, as active users of data (Ruppert et al., 2017). Other envisioned functions of the electronic vaccination card were, however, side-lined, such as the implementation of a call-recall system, which was initially planned but has not been carried out so far. Nor were data flows between different registries enabled that would have allowed an effective targeting of the unvaccinated population. The Austrian case thus demonstrates that datafication and digitalization might indeed bring about new forms of citizenship and participation in public health, but that these depend upon data flows to be realised.

Conclusion

In this paper, we examined a seemingly mundane infrastructure of datafication and governance: immunisation registries. Despite their key role in immunisation governance, these registries have received little attention outside of epidemiology. Driven by an interest in datafication efforts – both successful and less successful projects – we compared Norwegian and Austrian registries, respectively. Using qualitative methods, we examined data flows that form part of vaccine registries and how these reflect but also produce particular styles of governance. We label these 'data intensive' governance in the Norwegian case and 'data hesitant' for our Austrian case. Importantly, our study goes beyond the technicalities that make data flow (which, as it turned out, are never just technicalities), but allows us to sketch the ways in which data flows tie together – or disconnect – different actors involved in vaccination governance, including the state, health care providers, and citizens. Summing up, we find a fundamental two-way relation between vaccine registries and the governance of collective and individual immunity: First, it is only when data begins to flow that immunization comes to *count* for public health. Second, and simultaneously, the very flow of data – or the lack thereof - is contingent upon and embedded in the sociotechnical conditions of governance, including relations of trust and responsibility among central actor groups including the state, health providers, and citizens.

In the Norwegian case, data flows from individual bodies to registries and back again to different users. Key to these data flows are the clear allocation of responsibilities and the link between data and vaccination, as well as tight couplings between different data sites. This flow of data and the ways in which immunisation data is made available to users forms part of the state's efforts towards collective immunity. The registry system in Norway is sustained by a collective of curators and users, technologies, legal instruments, and expertise. The individual responsibility for immunisation is a central part of making data flow in a 'good' way in the Norwegian context.

In the Austrian case, the allocation of responsibility and link between data and immunization are less standardised and more fragmented across different federal states. It becomes apparent here that such a fragmented organisation of data collection produces obstructions in the data flow and makes data less reliable as a source for research or policymaking. Moreover, the non-centralised and non-digitised organisation of data assigns even more responsibility to the individual to manage their own immunisation status (e.g., in the case of loss of paper-based records), and data practices are only loosely related to vaccination governance. At the same time, this renders the individual citizen invisible in data governance. The loosely organised character of the national immunisation program has not changed with the recent introduction of the electronic vaccination card that remains limited in its use. Now, as before, the flow of data is obstructed in different ways. This obstruction manifests itself, for instance, in the failure to include essential features such as call-recall functions for basic immunizations and booster vaccination. These frictions are reminders of Star and Ruhleder's (1996) argument that data infrastructures are never finished in that tools and features are added, tinkered with, abandoned, or contested.

Investigating vaccination governance in terms of its underlying data infrastructures provides insights into the role of registries in governance more generally. Such an approach should not privilege flows over non-flows but should treat these symmetrically and as regular features of governance. Non-flows, as much as data flows, produce and reflect politically and culturally specific relations between citizens, healthcare providers and the state. A better understanding of the sociotechnical distribution of rights, agency, and responsibilities regarding both data flows and immunization itself is particularly pertinent given the many political implications that vaccination registries have.

A comparative approach to data flows highlights the contingencies of data practices and helps reveal how the socio-materiality of data is deeply cultural and political. To us, a comparative approach is valuable and productive in the same way that is often deemed to be a burden: the very act of comparing raises more questions about the empirical object (Deville et al., 2016) that call for further comparative investigations as well as for more in-depth individual case studies. The current pandemic demonstrates the necessity of a (historically) situated way of looking at, first, what has come to count in immunisation and how data infrastructures enable immunisation practices, but also how such infrastructures of datafication are resisted and where resistance is located. As this paper shows, immunisation, as a historically established, but newly politicised policy area, can function as a platform from which to mobilise key questions for the future of the datafied welfare state (Dencik and Kaun, 2020), particularly as to how data practices establish concepts of responsible citizenship and new socio-political categories, such as who is immune enough and thus deserving of rights and privileges.

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References

Alastalo M and Helèn I (2021) A code for care and control: The PIN as an operator of interoperability in the Nordic welfare state. *History of the Human Sciences* 35(1): 242–265, DOI: 10.1177/09526951211017731.

Alver BG, Fjell TI and Ryymin T (2013) *Vitenskap og varme hender. Den Medisinske markedsplassen i Norge fra 1800 til i dag*. Oslo: Spartacus Forlag.

Amelang K and Bauer S (2019) Following the algorithm: How epidemiological risk-scores do accountability. *Social Studies of Science* 49(4): 476–502, DOI: 10.1177/0306312719862049.

Asdal K and Gradmann C (2014) Introduction: Science, Technology, Medicine – and the State: The Science-State Nexus in Scandinavia, 1850–1980. *Science in Context* 27(2): 177–86.

Balog JL (2012) A Three-Step Approach for Creating Successful Electronic Immunization Record Exchanges between Clinical Practice and Public Health. *Online Journal of Public Health Informatics* 4(3), DOI: 10.5210/ojphi.v4i3.4290.

Bates J, Lin Y-W and Goodale P (2016) Data journeys: Capturing the socio-material constitution of data objects and flows. *Big Data & Society* 3(2), DOI: 10.1177/2053951716654502.

Bauer S (2014) From Administrative Infrastructure to Biomedical Resource: Danish Population Registries, the "Scandinavian Laboratory," and the "Epidemiologist's Dream". *Science in Context* 27(2): 187-213.

Beaulieu A, Scharnhorst A and Wouters P (2007) Not Another Case Study: A Middle-Range Interrogation of Ethnographic Case Studies in the Exploration of E-science. *Science, Technology, & Human Values* 32(6): 672–692, DOI:10.1177/0162243907306188.

Bjerkestrand S (2016) Helsenorge.no - Nok en statlig lenkesamling. *Tidsskrift for den norske legeforeningen*, 4 August. Available at: https://tidsskriftet.no/2011/06/helsenorgeno-nok-en-statlig-lenkesamling (accessed 11.11.2023).

Bjørkdahl K and Druglitrø T (2019) When Authority Goes Viral: Digital Communication and Health Expertise on pandemi.no. In: Bjørkdahl K and Carlsen B (eds) *Pandemics, Publics, and Politics - Staging Responses to Public Health Crises*. Basingstoke: Palgrave Macmillan, pp. 75-91.

Boyd D and Crawford K (2012) Critical questions for big data: Provocations for a cultural, technological, and scholarly phenomenon. *Information, Communication & Society* 15(5): 662–679. https://doi.org/10.1080/1369118X.2012.678878.

Cakici B, Ruppert E and Scheel S (2019) Peopling Europe through Data Practices: Introduction to Special Issue. *Science Technology and Human Values* 45(2): 199–211. doi: 10.1177/0162243919897822.

Crowcroft N and Levy-Bruhl D (2017) Registries: An essential tool for maximising the health benefits of immunisation in the 21st century. *Euro Surveillance* 22(17): 30523.

Dencik L and Kaun A (2020) Datafication and the Welfare State. *Global Perspectives* 1(12912), DOI: 10.1525/gp.2020.12912.

Desrosières A (1998) *The Politics of Large Numbers: A History of Statistical Reasoning*. Cambridge, MA: Harvard University Press.

Deville J, Guggenheim M and Hrdličková Z (eds) (2016) *Practicing Comparison. Logics, Relations, Collaborations*. Manchester: Mattering Press.

Eklöf M (2016) *Variola & Vaccinia: Om massvaccination och folkhälsopolitik, vaccinforskning och läkaretik*. Malmköping: Exempla.

Friese C and Latimer J (2019) Entanglements in Health and Well-being: Working with Model Organisms in Biomedicine and Bioscience. *Medical Anthropology Quarterly* 33(1): 120–137, DOI:10.1111/maq.12489.

Geertz C (1973) *The interpretation of cultures*. New York: Basic Books

Gesundheitstelematikgesetz (2012) BGBl I 111/2012 Version 115/2020, 14 October. Available at: https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2020_I_115/BGBLA_2020_I_115.pdfsig (accessed 06.06.2022).

Høyer K (2019) Data as Promise: Reconfiguring Danish Public Health through Personalized Medicine. *Social Studies of Science* 49(4): 531–555, DOI:10.1177/0306312719858697.

Høyer K, Bauer S and Pickersgill M (2019) Datafication and Accountability in Public Health: Introduction to a Special Issue. *Social Studies of Science* 49(4): 459–475, DOI:10.1177/0306312719860202.

Høyer K, Tupasela A and Rasmussen MB (2017) Ethics Policies and Ethics Work in Cross-national Genetic Research and Data Sharing: Flows, Nonflows, and Overflows. *Science, Technology, & Human Values* 42(3): 381–404, DOI:10.1177/0162243916674321

Leonelli S (2020) Introduction: Learning from Data Journeys. In: Leonelli S and Tempini N (eds) *Data Journeys in the Sciences*. New York: Springer, pp.1–24.

Leonelli S and Tempini N (eds) (2020) *Data Journeys in the Sciences*. New York: Springer.

Lie E and Roll-Hansen H (2001) *Faktisk Talt: Statistikkens Historie i Norge*. Oslo: Universitetsforlaget.

Magnusson K, Nygård K, Methi F, Vold L and Telle K (2020) Occupational Risk of COVID-19 in the first versus second epidemic wave in Norway, 2020. *Eurosurveillance* 26(4), DOI: 10.2807/1560-7917.es.2021.26.40.2001875.

Mamelund S-E, Shelley-Egan C and Rogeberg O (2021) The association between socioeconomic status and pandemic influenza: Systematic review and meta-analysis. *PlosOne* 16(9), DOI: 10.1371/journal.pone.0244346.

Ministry of Health and Care Services (2019) *Strategy to increase the health competence in the public, 2019-2023 (Strategi for å øke helsekompetansen i befolkningen)*. Available at: https://www.regjeringen.no/contentassets/97bb7d5c2dbf46be91c9df38a4c94183/strategi-helsekompetanse-uu.pdf (accessed 11.11.2023).

National Broadcasting (NRK) (2011) *Your health is being digitalized. [Nå digitaliseres helsen din].* Available at: https://www.nrk.no/livsstil/na-digitaliseres-helsen-din-1.7674627 (accessed 22.03.2023).

National Institute of Public Health Norway (2014) About SYSVAK. *Norwegian Institute of Public Health*. Available at: https://www.fhi.no/en/hn/health-registries/norwegian-immunisation-registry-sysvak/about-sysvak/ (accessed 06.06.2022).

National Institute of Public Health Norway (2020) Emergency Preparedness Register for COVID-19 (Beredt C19). *Norwegian Institute of Public Health*, 24 November. Available at: https://www.fhi.no/en/id/infectious-diseases/coronavirus/emergency-preparedness-register-for-covid-19/ (accessed 06.06.2022).

Niewöhner J and Scheffer T (2010) Thickening Comparison: On the Multiple Facets of Comparability. In: Niewöhner J and Scheffer T (eds) *Thick Comparison: Reviving the Ethnographic Aspiration*. Leiden: Brill Publishing, pp. 1–15.

Paul KT (2016) "Saving lives": Adapting and adopting HPV vaccination in Austria. *Social Science & Medicine* 153: 193-200. https://doi.org/10.1016/j.socscimed.2016.02.006

Paul K and Haddad C (2019) Beyond evidence vs. truthiness: Towards a symmetrical approach to knowledge and ignorance in policy studies. *Policy Sciences* 52(2): 299–314.

Paul KT, Janny A and K. Riesinger K (2021) Austria's Digital Vaccination Registry: Stakeholder Views and Implications for Governance. *Vaccines 9*(12): 1495.

Paul KT and Loer K (2019) Contemporary vaccination policy in the European Union: tensions and dilemmas. *Journal of Public Health Policy* 4(2): 166–179.

Pichelstorfer A and Paul KT (2022) Unpacking the Role of Metrics in Global Vaccination Governance, *International Political Sociology* 16(2): 1-18.

Pebody R (2012) Vaccine Registers – Experiences from Europe and Elsewhere. *Eurosurveillance* 17(17), DOI:10.2807/ese.17.17.20159-en.

Pinel C and Svendsen MN (2021) In search of 'extra data': Making tissues flow from personal to personalised medicine. *Big Data & Society* 8(2), DOI:10.1177/20539517211035664.

Porter TM (1995) *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton, NJ: Princeton University Press.

Prainsack B and Gmeiner R (2008) Clean Soil and Common Ground: The Biopolitics of Human Embryonic Stem Cell Research in Austria. *Science as Culture* 17(4): 377–395.

Prainsack B and Wahlberg A (2013) Situated bio-regulation: Ethnographic sensibility at the interface of STS, policy studies and the social studies of medicine. *BioSocieties* 8: 336–359, DOI:10.1057/biosoc.2013.14.

Regjeringen.no (2011) no. 35/2011, 15 June.

Ruckenstein M and Dow Schüll N (2017) The Datafication of Health. *Annual Review of Anthropology* 46(1): 261–278.

Ruppert E, Engin I and Bigo D (2017) Data politics. *Big Data & Society* 4(2), DOI: 10.1177/2053951717717749.

Scott JC (1998) *Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven, CT: Yale University Press.

Star SL and Ruhleder K (1996) Steps toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research* 7(1): 111–134.

Thygesen LC, Daasnes C, Thaulow I and Brønnum-Hansen H (2011) Introduction to Danish (nationwide) registers on health and social issues: Structure, access, legislation and archives. *Scandinavian Journal of Public Health* 39(7): 12–16.

Tupasela A, Snell K and Tarkkala H (2020) The Nordic Data Imaginary. *Big Data & Society* 7(1), DOI:10.1177/2053951720907107.

World Health Organization (2020) WHO Vaccine-Preventable Diseases: Monitoring System – 2020 Global Summary. Available at: https://apps.who.int/immunisation_monitoring/globalsummary (accessed 06.06.2022).

APPENDIX

Interview partners

1. Senior public health official of federal state 1, Austria, 19 April 2018
2. Senior public health official of federal state 3, Austria, 7 May 2018
3. Data administrator, federal state 3, Austria, 8 May 2018
4. Senior public health official of federal state 2, Austria, 22 March 2018
5. Data administrator, federal state 2, Austria, 22 March 2018
6. Senior immunologist, Austria, 21 February 2018
7. Senior epidemiologist, Austria, 6 March 2018
8. Senior public health official of federal state 4, Austria, 24 May 2018
9. Senior statistician, Austria, 25 May 2018
10. Senior epidemiologist, Austria, 30 January 2019
11. Public official at the Infectious Disease Registries, Norway, 3 March 2021 (including follow-up email exchanges: 10 March 2021 and 11 March 2021) – conducted online
12. Public official at the Infectious Disease Registries, Norway, 3 March 2021- conducted online

Notes

1 Up to date vaccination rates can be found at Ourworldindata.org/vaccination.

2 For the CIP, the officials consider 100 % reporting of the immunizations; for the flu shot they estimate 20% underreporting.

3 The question of making vaccination mandatory by law was raised by different political groups but was quickly shut down by the Norwegian Director of Health, stating that 'trust' was a key value attached to the nation's vaccination strategy.

4 This resistance to centralized data infrastructures is also related to a quite recent recognition of epidemiology as a public health discipline in Austria. As a senior public health expert of the state agency responsible for public health critically commented on, clinicians are still taken more seriously in public health than epidemiologists (Interview 3).

5 Criticism of the non-use of registry data in Austria extends beyond the specific area of vaccination and researchers have only recently succeeded in lobbying for the establishment of the Austrian Micro Data Center (AMDC) that allows researchers to work with registry data.

6 The recent introduction of COVID-19 vaccines forms an exception to that, as for COVID-19 vaccines every act of immunisation is immediately entered into a centralized database.

7 See also Ministry of Health and Care Services (2019) where the ambitions of user participation is repeated and strengthened, and where helsenorge.no is a key service in these ambitions.

8 This was the case in the COVID-19 vaccine rollout, too, since citizens themselves had to sign up for regional vaccination waiting lists or rely on their GP to encourage them to do so. Furthermore, parents of infants must find a doctor and sometimes even have to purchase the vaccine themselves and take it to the doctor.

Who Knows What a Microbe is? The Variable Texture of Microbial Identity in Agricultural Products, Regulations, and Fields

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Abstract

Microbial products are becoming common alternatives for pesticides and fertilizers in light of the unsustainability of chemical products. What the microbes in these products are, though—that is, how they are enacted—varies across regulatory, research and development, and growing spaces, and that variation matters to how they are regulated. From document analyses, interviews, and ethnographic work with scientists, growers, and policy actors, we find that these microbes are epistemically uneven, sometimes with pinned-down identities, and sometimes with loosely woven textures with holes. Amid calls to tailor regulations specifically for these products, we suggest that regulations predicated on discrete identities and predictable and controllable functions will fail to account for all users' experiences, and that regulation may need to learn to live with the lacy texture of microbes across contexts.

Keywords: Microbes, Microbiomes, Agriculture, Biostimulant, Biofertilizer

Introduction

Conventional agriculture runs on inputs—not just oil into tractors, but also into soil. The petro-derived fertilizers that drove the 'green revolution' continue to shape agricultural soils, still largely conceived as inert substrates. Nitrogen, phosphorus, potassium and pesticides are poured into and onto soils to support crop growth and yield, with 'yield' defined in the short-term through a single season's production and profit rather than through the land's long-term fertility. Meanwhile, regenerative, biodynamic, and other sustainability-minded forms of agriculture have long approached fields as richly multispecies endeavours of plants, animals, insects, and the microscopic life inhabiting and making up the soil itself. While the idea of microbial inoculants has been around in US agriculture for more than a century, it is now more prevalent in conventional systems, where multispecies considerations of agriculture (agroecology) have become part of company narratives toward more self-sustaining soils and more sustainable futures. 'Soil health' is becoming a centrepiece in sustainability conversations, even within Big Ag (Krzwoszynska and Marchesi, 2020), and noticing the importance of microbial worlds has become a prominent discourse in social science, whether in discussions of soil and agriculture (e.g., Lyons, 2020; Puig de la Bellacasa, 2017, 2019) or the human body and other geographies (e.g., Lorimer, 2020; Greenhough et al., 2020). 'Healthy' bodies and soils are coming to be understood as integrated ecosystems—as homes for many living things or even as living things themselves-- not merely inert matrices to support crops. Our interest in this paper is to investigate how microbial identity is understood in a rapidly expanding industry and how, specifically, *what a microbe is*, is enacted by different groups (R&D scientists, regulators, and growers) as beneficial agricultural inputs.

In this context, the green revolution's chemical inputs are now understood to be both unsustainable and potentially toxic to soil life (Pingali, 2012; Banjeree et al., 2019). But, because yields need to be sustained and/or increased and soil health has often been compromised, inputs cannot easily be eliminated. Instead, product makers are turning towards creating replacements that support longer views of agricultural sustainability. Simultaneously, scientific and societal appreciation for the value of microbes in supporting the health of many environments has expanded, as have technologies for understanding and employing them (Paxson and Helmreich, 2014). Consequently, agricultural products containing microbes or microbially derived compounds are increasingly being explored in conventional field cropping systems to support crop growth, suppress pests, and sustain soil ecosystems. Most agricultural giants such as Bayer (which acquired Monsanto in 2018) and Corteva (a subsidiary of Dow Chemical) now sport microbial product amendment lines. Although such amendments are only occasionally one-to-one replacements for non-living chemical products, in the absence of regulations developed specifically for microbe-based products, microbes tend to be subject to regulations similar to their chemical predecessors.

In this study, we ask: how is microbial identity enacted when living microbial products are slotted into regulatory frameworks designed for non-living chemical products? How do research-and-development (R&D) scientists, growers, regulators, and regulations make sense of the microbes in these products? And where might tensions exist between microbial products and the expectations applied to them? We draw on 23 interviews with scientists employed at companies that make these products, agriculturalists who use them, and stakeholders working in and around agricultural policymaking in the United States. We asked about the microbes with which they work, the types of products to which those microbes contribute, and their perspectives on current and potential future regulatory architectures for those products. We then contextualised what they said in the wider academic, grey, and industry literature about the role of microbes in growing crops. In addition, we conducted a more in-depth ethnographic project at a small agricultural microbial company. This project is the focus of a different paper in preparation, but the data certainly inform the discussion here.

What we found were different enactments of microbial identity in each sector. In the realm of policy, regulations require pinned-down, discrete microbial (genetic and functional) identities. In turn, scientists working for the companies that produce these products must *choose* how (by what method) to pin an identity onto microbes, in addition to choosing which genetic or functional identities to include in a product. In contrast, growers gather data about microbial identity differently; that is, through their sense-able presences as expressed through the complex interactions that comprise a field—that is, as a gestalt rather than as a species or even a function. Moreover, they do so through assembling those observations across time, characterizing a microbe as a pattern or an effect rather than a discrete thing such as a species name or a genome sequence. This ontoepistemic disconnect between microbial identities on labels and microbial identities in fields suggests that regulatory frameworks—even if configured for microbes as microbes, rather than as chemical-equivalents—will likely be unable to account for how microbial identity is enacted in any practical sense.

But more than that, our analysis points to a possibility that because microbes are indeterminate in multiple ways, *no one* may know what a microbe is *across* these shifting contexts—from lab to production line to agricultural field, for example—because microbial identity varies unpredictably and unevenly across them. Further, this lack of coherence might not be resolved simply by learning more about agricultural microbes, or by implementing one standardised view. That is, the gap between what a microbe is on a label and what a microbe is in a field is not a "productive" form of not-knowing that enables scientists to continue pursuing further epistemic certainty indefinitely (Lehman, 2021; Reinecke and Bimm, 2022). Rather, we argue that sites or regions of microbial unknowability may be a feature of more-than-human agricultural landscapes that current regulatory frameworks have difficulty acknowledging. We wonder about the capacity of these frameworks to allow microbes to be as uneven as the texture of agricultural microbial enactments are themselves.

The uneven texture of microbial enactments

Copious scholarship in the tradition of actor-network theory and material-semiotics tells us that our epistemic makings of what 'things' are—microbes per se—are not only constructed *in* practice, but also are assembled differently *through* multiple practices, such that further work is required to assemble these into a shared sense of a stable thing (e.g., Mol, 2003). As such, rather than thinking of things as continuous, congruous, and smooth across their enactments, we might be better off thinking about the texture of things across enactments as being a variable, dynamic, uneven, and inconsistent fabric. Some ideas of things are dense, relatively immobile, solid, more shared across practices and more stable. Others are patchy, uneven, loosely woven with holes, invisibilities, and inconsistencies; they are "slippery" as are, for example, enactments of wild and farmed salmon (Lien and Law, 2011). Because things are assembled and these assemblages are textured like fabrics, perspective matters; the location in the fabric matters; 'the same thing' may not be the same thing to everyone, everywhere, everywhen, and therefore what we know about microbes is always factish, or provisional (Latour, 2012; Flachs, 2019). A microbe on a product label might be a taxonomic genus or a quantity of spores, whereas in a lab that 'same microbe' may be a phenotype under a microscope or petri dish, and in a field, in that 'same microbe' might appear through other cues such as plants with healthy roots.

In asking "who knows what a microbe is?", we take inspiration from Annemarie Mol's question: "who knows what a woman is?" (Mol, 2015). Mol's point is to demonstrate that a woman is not a very tightly woven thing; different disciplines (and ways of knowing beyond academia) have very different ideas about the answer to the question of what a woman is and are linked to who is doing the knowing, how the knowing is done, and whom the knowing is for. We want to make a similar move here. Microbes are like women. While some microbiologists learn about microbes by growing them in isolated cultures, others do so by sequencing community DNA from samples of soil or seawater, with the potential for strikingly different conclusions about which microbes exist and what they can do. Since microbial product regulation relies on knowledge claims about microbes, we need to get at the texture of the fabric—how different enactments of microbes are

Figure 1. Lacy fabric: discrete flowers in a field of holes

assembled—to understand the work that regulations might or might not be able to do.

Further, these variable epistemic enactments and subsequent assemblages of what things *are,* are not easily separable from their ontological properties. As has been demonstrated elsewhere across the growing critical microbe-studies literature, microbes are also ontologically complex and hard to pin down (O'Malley, 2014); taxonomic designations, for example, such as species, do a poor job of containing them (Ward et al, 2008; Murray et al., 2021) and the metabolic and phenotypic aspects of microbes that we use to characterize them *functionally*, change readily across time and space (e.g., Nguyen et al., 2021). We therefore began this analysis of agricultural microbiome products with the expectation that the fabric of how microbes are known in agricultural products would not be smooth and solid. After investigating practices that enact microbes across agricultural-product contexts (regulation, R&D, and agricultural practice), we have come to think of them as them lacy: woven so that in some places discrete notions of what microbes are, are formed—blossoms or flourishes in the fabric; moments of discrete knownness through labels or lab results—but in between these, a sort of gauze; a slippery fabric filled with holes (Figure 1). Microbes as we know them—that is, human enactments of microbial life in various contexts—feel like islands of knowing, flowers in the gauze, but are only ever single states of microbe-ness from single vantage points (giving them 'interpretable flexibility' a concept that itself has been somewhat flexy (e.g., Leigh-Star, 2010; or Fish, 1980). In any case, try to pin down a microbe and they're inclined to slip—something we see even in regulatory frameworks designed around an assumption of fixedness.

This sense of microbial not-quiteness and the multiplicitous interpretations of microbes by various stakeholders make microbes rich and delightful subjects for critical analysis, but troublesome subjects for regulation. Regulatory bodies such as the US Food and Drug Administration (FDA) and the US Environmental Protection Agency (EPA) *do* make regulations around microbes. However, the regulations they make can cause plenty of trouble for, for example, artisan cheesemakers, whose ways of knowing what good cheese is—meticulous production practices, evaluation via visual and olfactory cues, etc.—don't always align with how the FDA knows what constitutes a safe food product (Paxson, 2008). Regulations around agricultural microbial products similarly attempt to sort 'good' or safe microbes from 'bad'" or dangerous ones through enactments of microbes that do not necessarily align with how agriculturalists judge microbes. Further, R&D scientists' inside knowledge of their microbial product's capabilities also only partially aligns with the judgements that regulations require. Herein lies the trouble: making regulatory enactments of microbes meaningful to scientist and grower enactments of microbes requires a lot of work, and sometimes does not work at all. Much of the challenge seems to lie in the difference between the solid-ish moments of "'knowing'" (e.g., obtained by lab results and presented on labels) and the quite varied textures of how growers know microbes once they are in the field. So, our question becomes: who knows what a microbe is? When, where and how do they know it? In the next section, we discuss the ways in which microbes are slippery to begin with, and in the subsequent sections we discuss the modes of enacting microbes in regulations and R&D. Finally, we think about how growers enact microbes and what discrepancies among these perspectives this means for our abilities (or inabilities) to even know what a microbe is?

Microbial identity: slippage in taxonomic and functional classifications lead to epistemic inconsistencies

Humans come to know microbes through diverse practices, many of which do not extend from modern Western microbiology (e.g., Giraldo-Herrera, 2018; Hey, 2019; Muenster, 2018). However, for the purposes of regulations and R&D settings in the US, we can say that microbes tend to be formally or officially categorised either taxonomically (e.g., phylum, species, strain) or functionally (e.g., 'Nitrogen-fixer' or 'Phosphorous-solubiliser'). Because one works in capacities as identified by humans and one works in genetic or morphological differences, these two systems of knowing microbes do not always produce the same distinctions, in ways that set up other kinds of epistemic inconsistencies.

Taxonomic classification is a prevalent way of knowing biological life, but also a long-standing problem for microbes. It is well-known that the concept of species doesn't work well for bacteria, yeast, and fungi (e.g., Doolittle and Papke, 2006; Staley, 2006). Microbes are prone to exchanging genetic material 'horizontally' with other cells in ways that often disrupt two core taxonomic principles: the assumption that any one creature has one and only one fixed genome throughout its lifetime, and the idea of a 'species barrier' that means members of different species are less likely to mate, combine their genomic material, and produce viable offspring. Microbes also trouble ideas of phylogenetic 'trees' with tidily branching paths that begin with common ancestors and feather out into families of more recently differentiated cousins. Instead, maps of microbial relations are highly rhizomatic and reticulate.

Nevertheless, in the absence of a yet widely accepted alternative way to handle taxonomy (though see Hedlund and Whitman, 2022), microbes remain known via species, delineated by genetic material. Species designations also underpin most agricultural microbial regulation. One common point of reference are designations made by the Animal and Plant Health Inspection Service (APHIS) which uses the prevalent pathogen lists (e.g., Center for Invasive Species and Ecosystem Health, 2018a, 2018b) to delineate species that may be moved across state lines with and without permits, such as native or naturalised plant pests or biocontrol agents (APHIS, 2020). The federal Health & Human Services and the US Department of Agriculture (USDA) also maintain the Select Agent Program which, in 2021, contained 233 microorganismal species (including viruses) that are considered severe threats "to public health and safety and to animal health or products" (USDA, 2021). Corporate researchers who want to include such species in commercial products would be hard pressed to demonstrate the safety of these 'outlaw' microbes, though there are occasional exceptions, one of which, a *Burkholderia* species, will be detailed below. If there is enough literature supporting the safety of a particular strain, some microbes become generally recognised as safe and are easier to pass through both federal and state regulations (as discussed later). However, far more microbes occupy regulatory grey zones, that is, neither generally recognised as safe nor outlawed—either because they remain taxonomically ambiguous (such as in the case of microbes newly 'discovered' through bioprospecting) or because their range of potential behaviours cannot be cleanly predicted.

Functional classification of microbes, or the grouping together of microbes by their metabolic capacities or effects on organisms or ecosystems, is also quite prevalent in R&D settings. In practice, species designations are not always the most useful way to classify microbes in agriculture for reasons that have nothing to do with taxonomic messiness; rather it is that multiple kinds of microbes may perform the same agronomic job (in ecologies this is sometimes called functional redundancy). Researchers and other humans who work with microbes often talk about them in terms of their signature function or capacity, that is, the *capabilities* that professions or industries value most among the repertoire of what a given microbe can do. For practical purposes in agriculture, it may be less useful to know a taxonomic designation such as species or strain names and more salient to know that a microbial community includes a nitrogen-fixer, phosphorous-solubiliser, or a fungicidal bacteria.

The conflation of species identity and functional capacity creates a tension for regulating and using microbe-based agricultural products because a species name on the label does not always stably align with a single set of functions that this species will reliably perform. Labels are required to describe what a product does, but what a product does may change with how and where it is used. Microbes, like other living things, respond to their environments. Moreover, they may also undergo genetic changes as they reproduce and dwell with others, so that the microbe that goes into the bottle may not be identical to the microbe that proliferates in the field in either genome-based taxonomic or functional terms.

This imperfect alignment between taxonomy and function becomes important for companies that must defend, simultaneously, the safety and efficacy of their products. Companies, in keeping with contemporary practice in other industries and research areas, may establish microbial taxonomic identity by sequencing only a small portion of a strain's DNA (a portion often known as 16S) However, this portion of the DNA may, indeed, is likely—to remain stable even as other changes occur that matter to a microbe's phenotype or functional capacity (Terzaghi and O'Hara, 1990). Consequently, when microbes are identified via 16S, taxonomic and functional identities may not move in lockstep.

Not all ways of knowing microbes revolve around species. Growers and extension scientists gather data differently and may know microbes through observation of crop health or soil texture or changes that occur in crops and soils over seasons and decades. Microbes influence nutritional status or field quality in ways that can be perceived sensorily: green plants, rapid growth rates, rich black soils, vigorous root growth shown off on agricultural microbe social media, or gestalt senses of crop-soil complex 'health'. In agricultural praxis, knowing what is effective often comes through accumulated experience over time and across contexts, looking for patterns across multiple 'reaction norms' or range of observed variation of a crop, a field, or of a microbe-containing agricultural product (Figure 2). Growers and plant breeders have long understood that there is no such thing as a ubiquitously good crop variety, that is, one which is always good in all years, fields, conditions, etc. Further, the challenge of predicting crop performance has grown only more difficult in the weird environments produced by climate change (Iizumi and Ramankutty, 2016; van Etten et al, 2019). Decisions about what varieties to plant are often made based on long-term, cumulative, and often intuitive knowledge and then bet-hedging against unpredictability. In the past, in large-scale contemporary monocultures, the slopes of linear crop reaction norms that have helped predict performance and major crop-environment interactions have been relatively well-characterised. More to the point, crops planted anew each year from commercial seed do not mutate, exchange genes, or otherwise evolve within or across generations. Microbes, which do mutate, exchange, and evolve rapidly, are less linearly predictable than plants; they also have shorter histories of deliberate human observation. For microbes, there are more spaces of unknowability that cannot necessarily be predicted across time, environment, and context; a difficult place from which to regulate.

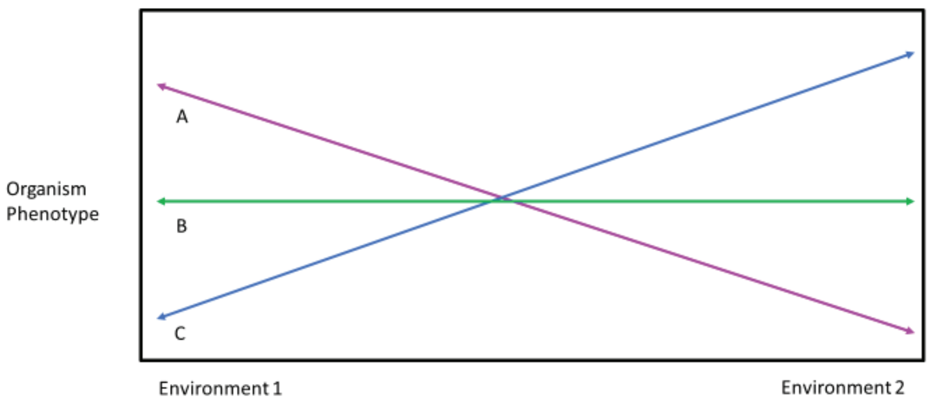

Figure 2. Reaction Norms. Growers expect that living things will vary across environments. Reaction norms are a commonly employed visual in agriculture to describe variability of living things, e.g., crops across environments. "Environments" can be considered as any number of contexts such as fields, locations, years, or different conditions such as high and low rainfall.

What regulators know a microbe to be

We begin with how regulations ‘know’ microbes or, in other words, with how microbes are enacted through microbial product categories. Regulations dictate microbial product categories (e.g., biopesticide) for labels and markets. Defining these categories is central to enactment of commercial agricultural microbes. Mirroring the categories employed for synthetic chemical products, microbe-containing products are most often classified either under biopesticides or biofertilizers/biostimulants. Because different categories of agricultural products are regulated by different agencies, producers think about which regulating body they will face before making discrete claims about individual products and the ingredients they contain. Those claims may be only tenuously connected to the potential activities of the microbes inside the bottle in that many microbes do many things and only one of those functions need be listed on a label. Therefore, regulations apply to what a company *claims* a product does—and companies are not obliged to openly claim that their microbes have all the functions they may know them to have.

In the United States, any agricultural product that claims to kill things (to work as a pesticide) is subject to regulations set by the federal Environmental Protection Agency (EPA).[1] This includes chemical and biopesticides: fungicides that kill fungi, herbicides that kill plants, insecticides that kill insects, and so on. Once “pesticidal intent” is claimed, a product‘s risk is evaluated on the basis of its individual *ingredients*. Microbes, in this case, are an ingredient. For every taxonomically distinguished microbe in a -cidal product, a company must provide evidence that that microbe is safe for non-target organisms (it kills only the organisms it is meant to). For microbes already characterised for agricultural use, adequate evidence can come from an existing body of literature. For unfamiliar microbes, companies must make statements about both taxonomy and provide proof of non-toxicity, either of which may raise a rationale for refusing product approval.

In contrast, products which claim life-*stimulating* effects—biofertilizers and biostimulants—are not typically regulated by the EPA, but by individual state governments as each sees fit.[2] Such products encompass a range of plant nutrition-supporting functions beyond basic fertilizers such as avoiding, correcting, or preventing nutrition-based plant disorders (e.g., blossom end rot, or chlorosis, etc.); improving soil or seed nutrient conditions for better root growth; supporting or improving organic matter biodegradation; optimizing soil conditions for increased ‘plant vigour’ or ‘abiotic stress resistance’; improving overall plant nutrition or nutrient uptake; and so on (EPA, 2023). The modes of action through which microbes may perform these functions are similarly varied. The EPA also judges certain modes of (non-pesticidal) biostimulant action (known as plant growth regulators (PGRs)) to fall under its authority as “enhancing, promoting, or stimulating fruit growth and development; inhibiting or promoting sprouting; inducing, promoting, retarding, or suppressing seed germination; and enhancing or promoting crop, fruit, or produce colour, development, quality, or shape”. So, not only are the positioning of a microbial pesticide and its subsequent regulation defined by the claims of the producer, the modes of microbial action which subject a product to EPA regulations are slippery. It can be quite tricky to distinguish a product that promotes vigorous plants from a product that promotes things attached to vigour such as fruit development or quality because these effects often travel together. Therefore, where, by whom and for which qualities a microbe is identified and regulated is slippery fabric to begin with.

The EPA requires that microbes employed in products under its jurisdiction be “deposit[ed] in a nationally recognised culture collection.” For a microbial species to be recognised as a species with an internationally authoritative species name, it must be held in pure culture in two separate, internationally recognised culture collections. (This requirement raises issues for microbes that cannot be cultured or depend on the presence of another organism for survival, and the global microbial taxonomy community is reconsidering and revising it.) In fact, the microbial product (and intellectual property) worlds often operate at the level of *strain*, a finer distinction than species. Bacteria evolve quickly and thus exhibit a high degree of genetic variability. Maintenance of a particular strain within a species becomes a way for product developers to attempt to ensure more specific functionality and ownership of particular genetic variants within species. EPA regulations state that "each new isolate for which registration is sought have a unique identifier following the taxonomic name of the microorganism, and the registration application must be supported by data" both to indicate that the strain is what the company claims it to be, and that it is the same or different than strains that have been registered and used before. The EPA has this to say about confirming microbial product identity:

The product analysis data requirements for microbial pest control agents (MPCAs) parallel those for conventional chemical pesticides... However, due to the unique nature, composition, and mode of action of the MPCAs, there are some important differences. For example, protozoa, bacteria, fungi, and viruses should be identified to the extent possible by taxonomic position, serotype, composition, and strain, or by any other appropriate specific means. This information would take the place of chemical name and structure information for conventional chemical pesticides. In addition, the Agency must be reasonably assured that the methods used and the data submitted are capable of demonstrating that the microbial pesticide used in the field is the same as that which was tested for safety. (EPA, biopesticide registration section on the website, 2021).

There is much ambiguity to take note of here; the EPA requires microbes be identified *to the extent possible* suggests that even in formal regulatory documents there may be implicit recognition, if not direct articulation of the difficulty of knowing what a microbe is. Regarding other squishy language in this passage, interviewees tell us that in practice, what the EPA means by "reasonable assurance" is determined on a case-by-case basis. But, at least in some cases, this means that proof the pesticide tested is the same as the pesticide applied requires a comparison of genetic or metabolite data from the field to the original lab tests.

The EPA (and some state-level regulatory bodies) will not approve some species under any circumstances because they cause harm or are related to pathogens that cause harm to human, animal, or plant life. For example, the genus *Burkholderia* is (in-theory) off-limits because some members are responsible for a variety of human, domestic animal, and plant diseases, including several species considered to be potential biological warfare agents (Compant et al, 2008). In other taxa, judgements are made at the strain level, as is the case for members of the species *Pseudomonas aeruginosa*. *Pseudomonas* is a close taxonomic cousin of *Burkholderia*, enough so that some species have been moved back and forth between those two groups over time and taxonomic disagreements. *P. aeruginosa* is ubiquitous in soil, water, and built environments. However, some strains are opportunistic pathogens responsible for life-threatening lung infections in people with cystic fibrosis. We interviewed researchers from one company that sought approval for a *Burkholderia*-containing biopesticide product with confirmation of non-pathogenicity obtained directly from the Cystic Fibrosis Foundation. Even so, the EPA required that live microbes be replaced with heat-killed ones. This was possible in this case because the active ingredient was a microbial metabolite retained in the final product, but an additional step and deal-breaker for living microbial products. In the end, a live organism was literally reshaped to look like a chemical product.

Such judgements are even slipperier because pathogenicity is often not a property of a microbe but of a context. Many sometimes-pathogens are routinely present in environments where they do not cause disease, only becoming a problem when environmental disruption gives them room to grow. *P. aeruginosa* is probably dwelling with you right now, wherever you are reading this paper. Unless you have a respiratory disorder, this should cause you no concern; the human respiratory tract is typically efficient at trapping and sweeping inhaled bacteria into the back of the throat where they can be harmlessly swallowed. If you have cystic fibrosis, however, or a disorder that changes how trapping mucus and sweeping cilia function to keep your respiratory tract clean, inhaled *P. aeruginosa* cells can stay put in the lower reaches of your lungs, reproduce, and build antibiotic-resistant biofilms. *P. aeruginosa* only forms biofilms when gathered as a sizable community or'quorum' of cells, making them a non-issue when small numbers of cells are regularly cleared out. *P. aeruginosa* becomes a different kind of microbe in the lungs of someone with cystic fibrosis, with distinctive and situationally pathogenic characteristics. *Clostridium difficile* is another well-known example of a microbe that *becomes* pathogenic, rather than *being* a pathogen; ordinarily present in small numbers in every human gut, it causes disease and even death when sustained antibiotic exposure kills large segments of someone's normal flora, leaving an unusually large ecological niche for the antibiotic-resistant 'C diff' to fill.

Examples of such contextual pathogens abound in agriculture. For example, most microbial species that cause the multi-etiology disease known as 'root rot,' such as *Alternaria*, *Botrytis*, and *Fusarium*, routinely live in agricultural soils. But, it takes it takes damp or otherwise conducive environmental conditions for disease to occur. Certainly, recommending any of these species as a microbial amendment would be hard going, just as arguing for *C. difficile* as a probiotic would be. However, if disease were diagnosed on mere presence of a potential pathogen, then every field and every human would be diseased, even when they clearly are not suffering symptoms. And not all cases are as clear-cut. As we will see in the following section, one of the most favoured agricultural microbes, *Bacillus subtilis*, can occupy different places in the lacy fabric as 'beneficial' or '-cidal' depending both on context and the epistemic point of view from which it is enacted.

For products that do not belong to the EPA remit, individual state agencies must choose how to regulate them. Many state-level regulations are concerned with accurate labeling: does the product contain the microbe (and the amount of microbe) on the label and do what the company claims? However, the evidence that companies must provide to address that concern varies. Under relatively strict Oregon regulations, the term 'biostimulant' is considered one of several "undefined" and "misleading" terms not allowed on packaging.[3] What are then called biofertilizers or require comprehensive lists of ingredients and their derivations, plus heavy metal testing reports detailing how the testing was done. Some ingredients, including certain acids and "waste-derived" products, require additional data. Live microbes trigger additional content-verification requirements: an "agricultural amendment product label" (Figure 3), detailing the "number of viable organisms" by weight or volume (typically reported as spores or colony forming units, CFUs) plus a warning statement for all microorganisms established by the American Biological Safety Association (ABSA) to carry an "elevated risk" of human pathogenicity (Oregon Department of Agriculture, 2023). There is, again, a list of bad actors. While each of these modes of pinning down microbial identity comes with its own set of epistemic negotiations, by the time they come to bear upon product regulation, the evidence poured into each taxonomic delineation or list or set of literature has been reduced to a point, a discrete microbial identity that falls to one side or the other of a line that separates acceptable from unacceptable.

At the opposite extreme, Texas operates on what is effectively an honour system. Several interlocuters told us that registering a biostimulant in Texas requires nothing more than mailing in a payment. Therefore, the same microbe—name, genome, and documented function—may be transformed from threatening to non-threatening simply by crossing state lines. Yet whether ingredients raise concerns or not, companies must apply for product approval, separately, from each state in which they wish to be allowed to sell that product—a significant regulatory burden that shapes the claims they choose to make and where they choose to make them in ways independent of the *potential* capabilities of the microbes they contain.

What R&D scientists know a microbe to be

As we have described, microbial products are primarily regulated based on claims made, and secondarily on ingredients listed. The decision about whether to make a particular claim or not represents a branching point and presents challenges for manufacturers of biological products. For example, a company might observe that microbes used in a product have both killing and stimulating properties. By choosing to claim that the product functions as a biostimulant, they may avoid EPA regulations entirely and only seek approval from those states in which they plan to market it. The very same product could also be marketed as a biopesticide, without anything changing other than the words on the label and regulating agency.

The cost of seeking EPA approval for a new biopesticide can be substantial (particularly for multi-microbe, i.e., multi-ingredient products), so small companies with limited resources may favour seeking approval for products as biostimulants to avoid that burden. They can do so without modifying the composition of the product because the same microbes may have multiple functions or may do different things in different environments. This is to say, outside of regulatory contexts, the distinctions between biostimulants and biopesticides—the difference between which facilitates life and that which facilitates death—may not be clear. Indeed, it may not exist at all.

Among entrepreneurs and scientists, however, microbial multiplicity is often a selling point: one product can do more than one thing. For example, *Bacillus subtilis* is well-known and loved for its plant growth-stimulating functions because (depending on the strain) it makes soil phosphorus more soluble and available for plant roots to absorb, 'fixes' inorganic nitrogen into plant-available organic nitrogen compounds or induces other plant growth-positive functions such as producing growth hormones.[4] But *B. subtilis* also secretes metabolites that damage fungal cell walls and performs other potential '-cidal' activities (Li et al., 2021). Scientists employed at biologicals companies, as well as technicians and growers who use *B. subtilis*-containing products, observe that they protect against common diseases caused by fungi such as *Pythium* and *Phytophthora*. Though scientific evidence remains correlative and not causative on this point, some also believe that *B. subtilis* affects plant health in broader ecosystemic ways by affecting the community structures of other soil microbiota; as numbers of *B. subtilis* increase in an ecosystem, numbers of other contextually pathogenic microorganisms decrease. *B. subtilis* appears to support 'healthy' soil microbial ecosystems, which in turn give fungi with pathogenic potential fewer opportunities to reproduce and take over in disease-causing numbers. By affecting fungal abundance, *B. subtilis* may appear to have fungicidal properties without ever committing fungicide at all.

Such modes or mechanisms of promoting soil or crop health also do not align well with regulatory assumptions largely inherited from chemical

Figure 3. Oregon Department of Agriculture, sample label for microbial product.

products. If a company wishes approval for a biopesticide, that product must pass regulations that assume that its *-cidal* effects occur through killing other organisms, even if the product's anti-fungal activity suppresses fungal growth through ways other than killing. Some companies can and sometimes do position a product as having both stimulant and -cidal effects. Yet many smaller companies with fewer resources rarely bother with that expense, preferring instead to compensate for mandated reductionist labels through nuanced conversation with consumers about multiple benefits. However, while microbial multiplicity and context-responsiveness can be attractive to the right consumers, these attributes can also be stumbling blocks in an industry where products have often been followed by the 'snake oil' accusation and purveyors would prefer to advertise products concisely to both consumers and R&D investors; unpredictability does not tend to be attractive in capitalist enterprises. In our interviews, representatives from large companies who *can* afford the regulatory expenses for multiple product positionings often argued for even stricter regulations as the solution for that reputation. But we wonder something slightly different: whether it is possible for any amount of regulation to contend with microbial functional identities if they are never one thing to begin with.

The troublesomeness of microbial multiplicity is true for taxonomic identities as well. As previously mentioned, data confirming species or strain are usually only required for novel or previously uncharacterised microbes. But what is a characterised microbe and where and when is it characterised? The trickiness of microbial identity is a source of regulatory instability for multiple reasons. For one, taxonomists sometimes revise classifications such that a microbe might be in a clade (a group with a presumed shared evolutionary history) recognised in the literature as generally safe one day and become a member of a more risky clade the next. For another, taxonomy is troublesome because living things evolve, and the microbe applied or what the microbe becomes in the field may not be identical to the microbe put into the bottle and cleared by regulatory processes. The implicit hope expressed by most R&D scientists for the fate of most agricultural microbial products is, of course, that they will survive, at least temporarily, in fields. However, much remains unknown about the persistence of product microbes or their long-term effects in soils because researchers have largely focused on functional traits rather than ecological traits related to a microbe's ability to establish in the field (Kaminsky et al., 2019).

What we *do* know is that microbes take up genetic material from their environments and often mutate as they reproduce. We know they routinely change which genes they *express*, and we know phenotypes and associated expression profiles in the field will differ from those tested in the lab. Taxonomic identity may or may not relate to functional identity, even beyond the functional multiplicity mentioned above. Put most simply, microbial identity may become something we have no way to predict; something that can only ever be enacted in a discrete way very briefly, at a particular place, in a single moment in time, and from a certain perspective.

Company R&D scientists are not thrilled by this kind of slipperiness because it complicates both marketing and intellectual property claims. It also complicates asking questions about what the long-term outcomes of microbial products will be, a topic in which regulators and growers have mutual interest. No one was willing to talk about risks on the record, but they were acknowledged by a small number of scientists, and some risks have been brought up in the literature for instance, by Jack et al. (2021) in a paper entitled "Microbial Inoculants: Silver Bullet or Microbial Jurassic Park?" Some companies compensate for other kinds of functional uncertainties by designing 'redundant' products—microbial mixes containing multiple species with the same theoretical capabilities (e.g., nitrogen-fixing)—in hope that if one species fails to 'do its job' in a particular environment, another will. "We are trying to compensate for environmental variability" one scientist told us about a biostimulant that contains twenty-one species of microbe. "We just want to make sure it works in as many soil types as possible." Functional redundancy also plays a role in how R&D scientists think about bioprospecting; if multiple microbes perform the same job, choosing one for a product can be a matter of choosing which one is easiest and cheapest to grow. In some ways, this reflects the way that growers tend to enact microbial identities: they don't particularly care who does the N-fixing or the pathogen suppression, they just need it to get done and their empirical observations of their fields are how they know if it does or does not.

What growers know a microbe to be

What growers need to know about microbial products is, at times, quite different than what either regulators or R&D scientists need to know. (It should be noted that 'grower' is a far from homogeneous category; the supervisor of an industrial-scale corn farm has a much different job and a much different set of empirical tools than an organic, local, multi-crop community-supported agriculture (CSA) farmer. That said, when we refer to 'growers' in this paper, we are speaking of data collected from individuals growing many different crops, but who all have frequent, critical-to-success, hands-on interactions with agricultural fields.) Federal regulations require knowing whether a microbe is a member of a presumed-safe species with no toxic effects. State regulations typically focus on a product's contents, safety to varying degrees, and the accuracy of its labelling. R&D scientists need to know whether they can correlate a microbe's genetic signature with a stable function under model conditions, and that a particular microbe fits within permissible regulatory categories. But the key question for an end-user has less to do with pinning down whom a microbe is and what it does, and more to do with how microbial actions manifest in the success of agroecological systems over time. What growers need to know is: How do microbes affect my fields and crops over days, weeks, seasons, and years?

No label can fully answer this question. Labels best describe what microbe-based products have been demonstrated to do in certain model and experimental conditions, and it is axiomatic in biology that lab conditions are not the field—let alone *your* particular field. On the contrary, as Maureen O'Malley (2015: 29) observes, it may be especially the case for microbes that "laboratory environments often select organisms for capacities they do not exhibit in the wild," suggesting it is more likely than not that what a microbe does in the field will be misaligned with what a lab-determined label can report.

Growers are savvy though, so, while regulators may strive to pin down islands of certainty in a sea of microbial slipperiness—discrete flowers in the gauzy lace—people who grow plants *expect* that living things will not always behave the same. Over time, they have come to *expect* unpredictability, and very few solid moments of knowing in an otherwise uncertain fabric. Growing is always gambling, we were told, but microbes are a form of bet-hedging in the same way that selecting the best seed variety for your field is bet-hedging. In fact, thinking about the contents of a microbial product as similar to the contents of a seed packet is helpful. A seed packet label suggests some properties of the contents but is also not necessarily a deterministic prediction of the results of planting them. You may plant a certain variety of tomato or pepper but depending on the year or the place –the variation in rain, wind, sun, soil, and other organism encounters— a plant may have larger leaves, fewer flowers, or fruits that vary in size, hue, or sweetness, or may even fail entirely. In these regular dealings with the dynamism of living organisms, many growers are already prepared to see microbes, who are likely to be even more variable than seeds, in the same fluctuating light. That is not to say that company scientists ignore the 'how does this product affect fields' question; obviously, if they are to be successful, it concerns them, too. But there is no single model field to be understood, and so this knowledge must be accumulated differently. Field R&D, which seems to sit somewhere in between the lab and grower experiences is a critical component of long-term commercial success, something that company scientists tell us will increase exponentially as the industry expands and tell us about the more distant futures of microbial identities. What we do know is that outside of some aggressively managed agricultural settings, most soil is replete with relatively stable microbial communities (Fierer and Jackson, 2006). New microbes introduced into robust communities may integrate or alternatively, fail to establish and die out relatively quickly (Debray et al, 2022). (It should be noted that many agricultural microbial communities are not considered robust, but rather, are labeled 'dysbiotic' after years of harmful conventional practices.)

Most growers do not directly care about whether an externally applied microbe integrates into a robust soil microbial ecology, but they do care about whether to expect a temporary or lasting effect on health or productivity. Answers to these questions do not usually come through a product label or a lab result.[5] Within a season, the growers we spoke with enact their ideas of microbial inoculants empirically. This might look to them like greenness, leafiness, stalk robustness, heavy seed heads, seed size, resilience in the face of drought, absence of disease, or the ever-important, livelihood-related metric of yield. Across seasons, this might look like darker, more tractable soil or greater consistency in yields. Many grower readings of microbial inoculants are even less discrete. A hemp grower in Colorado told us that things had just "gone better" since he had been inoculating his fields. Microbes are identified by growers through their experience—their discrete *and* gauzy observations of the collective phenotypes of the whole system of living things within which they are in *long-term* relations, including crops and other microbes.

Another grower spoke to us about the difficulty of trying to produce an organic crop on a field which had been in conventional wheat rotations for more than a decade. If they saw any sustained rainfall, these acres had a strong tendency towards outbreaks of root rot. Application of beneficial microbes backed it off more than once. An outbreak looked like rapidly spreading wilting, early signs of ultimately fatal collapse of plant vascular systems. Recovery after field inoculation with microbes meant that as long as a plant was not too far gone, they would stand straight again as their vascular system regained functionality. The absence of a robust soil microbiome and presence of introduced microbes certainly matters to growers, but in this case and others, microbial mattering was not read through label identities or functional mechanisms. Rather, the importance of microbial identity to growers was enacted through their observation of plant posture, through phenotypes that indicated regained future possibilities of health and crop productivity.

When microbes are applied without corresponding practices that sustain soils or as of single-microbe product 'fixes' that treat microbes like chemicals, microbial products are likely to act like chemicals too. That is, offering a one-time salve rather than any long-term salvation. Here, again, comes a challenge for aligning pinned-down regulatory identities with how growers know microbes. Growers look for larger organism and system phenotypes over varying timeframes. Growers expect inconsistencies. They expect living products—seeds, plants, and increasingly microbes—to exhibit a range of behaviours across years and changing environmental conditions. Short-term fixes are still fixes, and welcome, but not guarantees of what to expect next time and not necessarily as valuable as practices that move systems away from dysbiosis over the long-term. Growers know and will continue to come-to-know microbes through the patterns of lacey microbial fabric that they can make sense of over time. Rather than pinning down discrete enactment or flower in the lace, as a label might try to, growers are looking for only relative stability in how variable and uncertain threads weave together in the bigger picture of cultivation over years, decades, or even centuries. Whether a microbe is life-stimulating or -cidal or both, whether it makes yield go up or disease go down, and whether it is ultimately beneficial, harmful, or irrelevant is all a function of the agroecosystem pattern in which the microbe is somehow woven, but in which *what it is* and *what it does* is never precisely pinned down. While more data about how externally applied microbes behave across healthy and dysbiotic fields might better trace those microbial threads, they are very unlikely to change the metrics that growers apply to evaluating the texture of the fabric over time.

Discussion: Who knows what a microbe is?

Existing regulations demand and thus partially invent discrete microbial identities in efforts to predict and control their outcomes. But while this framework can be applied to microbes to generate lab results and labels with taxonomic status and prospective functions, these discrete ways that microbes can be known—the discrete flowers in the lacy fabric of microbes—are unlikely to have much to do with what microbes become as they move out into the more slippery parts of the fabric, the variable field contexts and long-term lives of agroecosystems where they become known in other ways, or become, perhaps in many ways, unknowable. The texture of microbial enactments is uneven, containing discrete identifiable moments amid lots of slippery gauze, so that trying to know microbes in *only* discrete ways limits what we can do with them. Yet in contrast to discrete labels and de-contextualised lab results, growers have no choice but to work in variable fields with dynamic living organisms. They must accumulate their knowledge about what microbes are differently, which means developing their own gestalt metrics, but also, critically, that these metrics hold space for what cannot be known and/or predicted about them.

Growers have no choice but to treat microbes as complex and uncertain if they want to work with them. This manifests in at least two main ways. First, growers come to know microbes through multispecies readings of the agroecosystem. If plants grow well, or are resilient through drought or disease, growers know microbes through that gestalt. They come to understand microbes through whole systems or nested systems such as soil quality or plant health. Second, growers come to know microbes over time. Whether it is a crop variety or a microbe, growers cannot rely on living things being reliable. Growers accumulate intuition about what 'works' over time and variable contexts are forced to make knowledge through complex co-productions in which patterns may become more predictable, even while individual elements within that pattern cannot be predicted or controlled.

Marketers, scientists, growers, executives, regulators, and lobbyists alike all say: we need more data on microbial agricultural products. The operating assumption across the community of interested parties is that contemporary Western humans have only just begun to work deliberately with microbes to support agriculture; consequently, uncertainties that currently characterise their regulation and use are a function of not yet knowing enough about how microbes behave in soil or in association with crops. On the basis of the investigation that we have described here, we would like to make a different suggestion. We agree wholeheartedly that microbes have been understudied and warrant more attention. Additional study may even help resolve them into more consistently regulatable entities. However, we are unconvinced that attempting to fit microbes into regulatory and other epistemic frameworks in which they are assumed to have fixed identities is practically helpful. Further, it is not an approach that accomplishes much toward understanding microbes in the complex, ecological, systemic senses in which they are most important to agroecosystems. More data, even from field trials under varied conditions, will not fully resolve this mismatch between a need for certainty and a reliance on intuition over time.

Microbial products fit poorly into regulatory frameworks not just because they are poorly understood, but because they challenge boundaries among products, environments, and contexts insofar as regulations assume microbial identity in ways that have not yet been (perhaps can never be) fully stabilised. It is our position that because regulatory frameworks make sense of microbes *only* in discrete ways that regulations may be *incapable* of making sense of what a microbe can be in the field. That is, in this epistemic space of regulations, though microbes are known in certain ways, they may be *unknowable* in the ways that ultimately matter to growers or in a larger ecological sense. It may eventually be possible that regulations can come to know them through observations that can encompass more multiplicity and dynamism, but what that might look like remains an open question.

One way to make sense of microbial complexity is to locate that complexity in ways of knowing rather than in microbes themselves. Talia Dan-Cohen (2016) distinguishes 'ontological complexity,' as a function of an object, from 'epistemological complexity,' produced through mismatches between an object and the paradigms or approaches applied to understand it. Epistemological complexity, in her account, describes the aspects of an object left unaccounted for by particular ways of studying it. Epistemological complexity may therefore *increase* when scientists gather more data because more discrete ways of understanding something may lead to more misalignments among those ways and not fewer. Distinguishing these two kinds of unknowability enables Dan-Cohen to explain how some early synthetic biologists might have been more successful in engineering biological systems *because* they were naïve about biology, not in spite of their naïveté; to them, biological systems looked simple because they had not yet made them complex.

We could describe soil-dwelling microbes as both ontologically and epistemologically complex. However, distinguishing the two implies that essential properties of an object of study can be identified independent of the epistemological approaches used to study them. Especially for microbes, the two cannot help but be tightly linked. While all observations are always mediated, ways of knowing microbes are less thoroughly stabilised than ways of knowing macrothings such as horses or tomato plants. Mediation matters more here because, as we have gestured to in this article, ways of knowing microbes—practices that contribute to assembling microbes are less ignorable than practices that assemble many other things. In short, we must describe microbes in agricultural products as onto-epistemologically complex. 'The same' microbe is made to be different things across varied contexts with no single, stable conceptual infrastructure to align them. Microbial unknowability is co-produced in the space among actors.

What does the laciness of agricultural microbes mean for regulating them? Some recent studies of ambiguity or non-knowledge have highlighted how not-knowing can be productively employed to sustain research fields, as in Reinecke and Bimm's (2022) analysis of Martian exobiologists' strategic maintenance of ambiguity to support continued funding for the search for life on Mars, even in the absence of any evidence for life on Mars. In contrast, Jessica Lehman's study of the study of ocean variability concluded that "increased data led not to a straightforwardly more accurate picture of the ocean but rather to fundamental uncertainty about how the ocean operates. (Lehman 2021: 856)" Lehman calls these uncertainties "productive limits" because while they limit, they also "demand a response" that manifests as ongoing genesis of ways of understanding uncertainty and the social infrastructure that strives to contend with it, albeit unevenly (Lehman, 2021: 856).

Our case differs from Lehman's because microbial laciness is not necessarily tied to the texture of the *human* social order through which microbes become known, but also often to the multispecies social order of how humans and microbes relate. Dominant epistemic frameworks are inadequate not just because of not what humans do with respect to other humans, but because of the mismatch between authoritative human ways of knowing and microbial modes of action. Microbes exceed and challenge categories established for non-living things (such as chemicals) that they are presumed to be like. They exceed and challenge categories for macroscale living things (such as plants) because their identities evolve differently. In addition to these limits of understanding being productive in terms of motivating efforts to learn, we see R&D scientists leaving open the possibility that microbial identities, functions, and capabilities exceed scientific ways to make sense of them.

Conclusion

How might a regulatory system grapple with microbial unknowability? Ways of knowing microbes cannot be perfectly aligned, and all are partial. Consequently, it won't do for regulators, or R&D scientists, or corporate lobbyists, or even growers to assert their own microbial heuristic as a standard by which the entire community should be organised. Instead, if the texture of microbial assemblages is uneven, then perhaps frameworks for regulating them should be, too. On the one hand, this suggestion is consistent with the patchiness of current practice. On the other, it may be in tension with movements to standardise agricultural microbial products and microbiome research and practice more generally. Regulations might come to be better informed by what growers already know about working with the uncertainty of living things, and perhaps metrics of microbial life taken in variable fields and knowledge gained over time will be a part of this. However, any regulation concerned with prediction and control will always be in tension with microbial life.Organizations including the Biological Products Industry Alliance and the Biostimulant Council (comprised of representatives from both biologicals-focused and conventional fertilizer corporations) are working to craft and advance specific legislation to regulate 'microbials' as more and different than replacements for chemicals. Progress is slow—a concern for many of our interviewees, but perhaps also an indication of the challenges of categorizing microbes and microbial products. Assembling a coherent and distinct idea of a biological-thing-as-regulated-product seems to require significant and contentious work. Ultimately, our findings suggest that the goal of that work might be best conceived not as trying to firmly pin down what these microbes are, but how regulations designed to ensure safety and efficacy can best account for how microbial fabric cannot be pinned down.

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References

APHIS (2020) APHIS Revises the Regulations for the Movement of Plant Pests and Biocontrol Agents. (Updated June 2, 2020). Available at: https://www.aphis.usda.gov/planthealth/330-regulation-lists (Accessed May 4, 2023).

Banerjee S, Walder F, Büchi L et al. (2019) Agricultural intensification reduces microbial network complexity and the abundance of keystone taxa in roots. *The ISME Journal* 13: 1722–1736.

Center for Invasive Species and Ecosystem Health (2018a) The Widely Prevalent Plant Pathogenic Bacteria List. Available at: https://www.prevalentbacteria.org/ (Accessed May 4, 2023).

Center for Invasive Species and Ecosystem Health (2018b) The Widely Prevalent Plant Pathogenic Fungi List. Available at: https://www.prevalentfungi.org/ (Accessed May 4, 2023).

Compant S, Nowak J and Coenye T, et al. (2008) Diversity and Occurrence of *Burkholderia Spp.* in the Natural Environment. *FEMS Microbiology Reviews* 32(4): 607–626.

Dan-Cohen T (2016) Ignoring Complexity: Epistemic Wagers and Knowledge Practices among Synthetic Biologists. *Science, Technology, & Human Values* 41(5): 899–921.

Debray R, Herbert RA, Jaffe AL, et al. (2022) Priority Effects in Microbiome Assembly. *Nature reviews. Microbiology* 20(2): 109–121.

Doolittle WF & Papke RT (2006) Genomics and the Bacterial Species Problem. *Genome biology* 7(9): 116–116.

EPA (2023) Biopesticide Registration. (Updated April 10, 2023). Available at: https://www.epa.gov/pesticide-registration/biopesticide-registration (Accessed May 4, 2023).

Fierer N and Jackson R (2006) Diversity and Biogeography of Soil Bacterial Communities. *Proceedings of the National Academy of Sciences - PNAS* 103(3): 626–631.

Fish SE (1980) *Is there a text in this class? : the authority of interpretive communities*. Cambridge: Harvard University Press.

Flachs A (2019) The Factish in the Field: An Anthropological Inquiry of Genetically Modified Seeds and Yields as Beings. *Science & Technology Studies* 32(3): 26–43.

Giraldo-Herrera CE (2018) *Microbes and Other Shamanic Beings.* Cham: Springer International Publishing.

Greenhough B, Read CJ, Lorimer J, et al. (2020) Setting the agenda for social science research on the human microbiome. *Palgrave Communications* 6(18).

Hedlund BP & Whitman WB. (2022) Towards a Unifying System for the Naming of Cultured and Uncultured Prokaryotes. *Nature Microbiology* 7:1514-1515.

Hey M (2019) Fermentation Praxis as Interspecies Communications. *PUBLIC* (59): 149-157.

Iizumi T and Ramankutty N (2016) Changes in Yield Variability of Major Crops for 1981-2010 Explained by Climate Change. *Environmental research letters* 11(3) 34003–34012.

Jack CN, Petipas RH, Cheeke TE, et al. (2021) Microbial Inoculants: Silver Bullet or Microbial Jurassic Park? *Trends in microbiology* 29(4): 299–308.

Kaminsky LM, Trexler RV, Malik RJ, et al. (2019) The Inherent Conflicts in Developing Soil Microbial Inoculants. *Trends in biotechnology* 37(2): 140–151.

Krzywoszynska A and Marchesi G (2020) Toward a Relational Materiality of Soils: Introduction. *Environmental Humanities* 12(1): 190–204.

Latour B (2010) *On the Modern Cult of the Factish Gods*. Durham: Duke University Press.

Lehman J (2021) Sea Change: The World Ocean Circulation Experiment and the Productive Limits of Ocean Variability. *Science, Technology and Human Values* 46(4): 839—862.

Li T, Li L, Du F, et al. (2021) Activity and Mechanism of Action of Antifungal Peptides from Microorganisms: A Review. *Molecules* 26(11): 3438.

Lien ME and Law J (2011) 'Emergent Aliens': On Salmon, Nature and Their Enactment. *Ethnos* 76(1): 65–87.

Lorimer J (2020*) The Probiotic Planet: Using Life to Manage Life*. Minneapolis: University of Minnesota Press.

Lyons K (2020) *Vital Decomposition: Soil Practitioners and Life Politics*. Durham: Duke University Press.

Mol A (2003) *The Body Multiple: Ontology in Medical Practice*. Durham: Duke University Press.

Mol A (2015) Who Knows What a Woman Is. *Medicine Anthropology Theory* 2(1): 57-75.

Muenster D (2018) Performing Alternative Agriculture: Critique and Recuperation in Zero Budget Natural Farming, South India. *Journal of Political Ecology* 25(1): 748-764.

Murray CS, Gao Y and Wu M (2021) Re-Evaluating the Evidence for a Universal Genetic Boundary Among Microbial Species. *Nature Communications* 12: 4059.

Nguyen J, Lara-Gutierrez J and Stocker R (2021) Environmental fluctuations and their effects on microbial communities, populations and individuals. *FEMS Microbiology Reviews* 45(4).

O'Malley MA (2014) *Philosophy of Microbiology.* Cambridge: Cambridge University Press.

Oregon Department of Agriculture (2023) Oregon Fertilizer Program Registration Guide. Available at: https://www.oregon.gov/oda/shared/Documents/Publications/PesticidesPARC/FertilizerProgramGuide.pdf (Accessed May 4 2023)

Paxson H (2008) Post-Pasteurian Cultures: The Microbiopolitics of Raw-Milk Cheese in the United States. *Cultural Anthropology* 23(1): 15–47.

Paxson H and Helmreich S (2014) The Perils and Promises of Microbial Abundance: Novel Natures and Model Ecosystems, From Artisanal Cheese to Alien Seas. *Social Studies of Science* 44(2): 165–193.

Pingali PL (2012) Green Revolution: Impacts, limits, and the Path Ahead. *PNAS* 109 (31): 12302-12308.

Puig de la Bellacasa M (2017) *Matters of Care: Speculative Ethics in More than Human Worlds.* Minneapolis: University of Minnesota Press.

Puig de la Bellacasa M (2019) Re-animating soils: Transforming human–soil affections through science, culture and community. *The Sociological Review* 67(2): 391–407.

Reinecke D and Bimm J (2022) The Maintenance of Ambiguity in Martian Exobiology. *Social Studies of Science* 52(2): 199–226.

Staley JT (2006) The Bacterial Species Dilemma and the Genomic–Phylogenetic Species Concept. *Philosophical Transactions of the Royal Society B: Biological Sciences* 361(1475): 1899–1909.

Star SL (2010). This is Not a Boundary Object: Reflections on the Origin of a Concept. *Science, Technology, & Human Values* 35(5): 601–617.

Terzaghi E and O'Hara M (1990) Microbial Plasticity: The Relevance to Microbial Ecology. *Advances in Microbial Ecology* (11): 431–460.

USDA (2021) 2021 Annual Report of the Federal Select Agent Program (Updated August 30, 2022) Available at: https://www.selectagents.gov (Accessed May 4, 2023).

van Etten J, de Sousa K, Aguilar A et al. (2019) Crop Variety Management for Climate Adaptation Supported by Citizen Science. *Proceedings of the National Academy of Sciences - PNAS* 116(10): 4194–4199.

Ward DM, Cohan FM, Bhaya D, et al. (2008) Genomics, Environmental Genomics and The Issue of Microbial Species. *Heredity* 100(2): 207–219.

Notes

1 Those products that are not pesticidal but are considered plant growth regulators (PGR) are regulated, like pesticides, under FIFRA (the Federal Insecticide, Fungicide and Rodenticide Act).

2 These mechanisms are potentially in flux. A bill which could eliminate EPA jurisdiction over biological products altogether, introduced in spring 2022, currently sits in the House "Subcommittee on Biotechnology, Horticulture and Research."

3 Words Oregon considers "undefined" and "misleading": balanced, health, stimulant, probiotic & catalyst.

4 While many strains of *B. subtilis* are known to be as beneficial, a few have been shown to cause disease in immunocompromised humans; and multi-antibacterial-resistant strains have turned up in hospitals: yet another example of the contextual identities of microbes.

5 Not surprisingly, there are an increasing number of companies offering to 'test' for certain microbes or 'whole microbiomes' in agricultural systems. How these companies go about establishing 'microbial identity' could be the subject of an entire article altogether.

Developing AI for Weather Prediction: Ethics of Design and Anxieties about Automation at the US Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography

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Abstract

The question of how professional and lay communities develop trust in new technologies, and automation in particular, has been a matter of lively debate. As a charismatic technology, artificial intelligence (A.I.) has been a common topic of these debates. This paper presents a case study of how the discourses and principles of ethics of technology development—specifically, of A.I.— were mobilized to form trust among actors in the fields of computer science, risk communication, and weather forecasting. My analysis draws on sociology of expertise and the literature on ethics of A.I. to ask: how emerging networks of expertise use ethics to overcome mistrust in technology? And, what role does the institutionalization of those networks play in the process of trust formation? I situate this discussion on the NSF Institute for Research on Trustworthy A.I. The Institute is positioned as a mediating organization with the goal of increasing trust in this technology primarily in the weather forecasting community, but also among the public. I show that first, to better understand how scientific and professional fields react to increased automation it is crucial to unpack the historical backdrop of how the professional identity of those experts has been shaped by a relationship with computer-supported modeling. To this end, I situate the discussion in the long-standing tensions between computer modelling and tacit knowledge in weather forecasting. Second, I argue that the means of establishing trust in A.I. propagated by the actors in the paper, which pair norms of explainability to sensitivity to professional intuitions and domain-specific conventions, rely on a series of 'mutual orientations' (Edwards, 1996). I mobilize the concept of 'mutual orientations' to describe the work of tailoring the ethics of A.I. to the specific requirements of weather sciences, but also to the vision of a national strategy of investment in this technology.

Keywords: Ethics of AI, Sociology of Expertise, Technological and Scientific Movements, Social Construction of Technology, Trust.

Introduction

Scientific expertise and moral values are intricately interwoven in the process of knowledge production (Shapin, 2008). Both federal funding agencies and academic researchers need to attest to the relevance of their technological and intellectual products by addressing the question of social relevance and ethical standards. This is the case with applied computational researchers. The question of how conceptions of ethics are legitimated and institutionalized gains critical importance during the contemporary acceleration of research on a form of artificial intelligence (AI) called machine learning (ML), as ML has proven to create epistemological and normative disruption in sciences and other professional fields (Kitchin, 2014). Ethics of design of algorithms and automation systems has been a site of an ongoing debate in and out of the academy (e.g., Dubber et al., 2020; Metcalf and Moss, 2019; Mittelstadt et al., 2016).

This paper explores the processes through which researchers working on applying ML to socially relevant issues legitimize and institutionalize their work by tailoring research to the emerging standards of ethics of AI. This discussion is empirically grounded in a partnership between AI researchers and weather forecasters. Weather forecasting is a generative site for theorizing how AI becomes embedded in scientific domains due to the long-standing tensions between computer modeling, automation, and tacit knowledge in the field—a jurisdictional struggle that AI has a capacity to exacerbate.

In this light, there is a need to understand better the processes through which ML and other forms of data-driven science become legitimized and institutionalized within domains where ML has previously played a marginal role. Furthermore, the paper asks: how do organizations involved in AI development resolve a tension between adapting external standards of ethics versus developing their own situated standards? I offer an analysis of the United States National Science Foundation's (NSF) Trustworthy AI Institute, which was established in 2020. The Institute has begun to develop ML for environmental sciences and weather forecasting. The bedrock of the Institute's operations is a design of ML that various communities of practice and potential users can trust. In this sense, the Institute's leaders attempt to frame the Institute as a mediating organization with the goal of increasing trust in the use of AI among environmental scientists, weather forecasters, and the public, but also to forge a closer partnership between the data analytics industry, government, and academia. This reworking of disciplinary and professional boundaries is centrally concerned with enabling innovation (Rottner, 2019) in the ability to predict future environmental conditions. The analysis of the Institute's multi-sector and multidisciplinary model is of relevance to the contemporary political and environmental milieu in which trust in the accuracy of weather and climate predictions is of high stakes.

The article explores how the conceptions of ethics, trust, algorithmic explainability, and adherence to the laws of atmospheric physics intersect in the design practices and discourse at the Institute. I show how a team of experts in AI, earth sciences, and risk assessment who were behind the Institute's formation set in motion a vision of the future of weather forecasting. This vision strives to fit into the prevailing imaginary of AI development and mitigate the mistrust in the technology among weather forecasters. Today's mistrust in AI on the part of the weather prediction community is a product of the long history of the external influence of computer science and modeling, which for over seven decades now has been shaping the identity of weather forecasters as an independent profession. I integrate a historical discussion into the article to locate the Institute's endevours within an established in the historiography of weather prediction theme of anxieties about automation and modelling.

The core theoretical contribution of the paper is a framework that describes stages of top-down and bottom-up 'mutual orientations' (Edwards, 1996) between a group of researchers and a federal funding agency towards institutionalization of an 'alternative expertise network' (Eyal, 2013) through reliance on a vision of civic, ethical, and trustworthy science. To do this, I appropriate the concept of 'mutual orientation' from a historian of science, Paul Edwards (1996). The concept means to capture a process of simultaneous alignment of objectives between a funding agency and a fundee. One of the reasons I choose to locate this inquiry on the case of implementation of AI in weather forecasting is the fact that the fears of "technological unemployment" (Keynes, 1930) are a long-standing issue in the history of weather forecasting (Harper, 2012). As such enduring conflicts between automation and tacit knowledge (Polanyi, 2009) can easily be ignored, one of the intended takeaways of the paper is to raise awareness about the need to consider disciplinary histories when analyzing the contemporary uptake of AI.

Methodology

To construct the paper's argument, I have relied on primary sources, including publicly available documents about the Institute (i.e., public presentations, online reports, calls for proposals) and peer-reviewed work of the Insititute's members. I transcribed recordings of Institiue-wide meetings, which I gained with the permission of the institute's directorate, and analyzed the transcripts according to the principles of content analysis. Furthermore, I used discourse analysis to capture policy discourses of the US AI strategy through reading NSF's and National Research Council's publications on trustworthiness. My reconstruction of the history of anxieties about automation in weather prediction was based on the reading of secondary literature.

Methodologically, I drew on a tradition of the social construction of technology (SCOT) (Pinch and Bijker, 1984) and the sociology of technological and scientific movements (TSIMs) and alternative expertise networks (Frickel and Gross, 2005). By adapting perspectives of the SCOT school of Science and Technology Studies (STS), I was able to examine processes of interpretative flexibility of trustworthy AI frameworks and the dynamics between designers and users of technology. Taking notice of the latter clarifications of the SCOT approach (Bijker, 1997), I attempted to pay special attention to shared 'technological frames' between designers and users of technology (trustworthy AI framework was one such framing device). I supplemented the SCOT methodology with a form of historical-sociological reconstruction of an alternative expertise network to capture its dynamic unfolding and a 'mutual orientation' towards an institutional (NSF's) vision of technology development.

This paper responds to scholarship parsing the problem of how trust is established between different groups of scientists and between users and designers of technology. The problem of mistrust among scientists most often emerges when groups of experts compete over the 'jurisdiction' (Abbott, 2014[1988]) for a specific task. Sociologists of expertise (Eyal, 2013) have asked how the 'jurisdictional struggle' between science and nonscience produces different forms of legitimation and institutionalization (Epstein, 1995, 2008; Gieryn, 1983; Star and Griesemer, 1989). I build on the contributions to this literature which focus specifically on how the creation of new and alternative expertise networks influences specific disciplines (Collins et al., 2007) and the problem of the jurisdictional struggle between scientific experts. Furthermore, to understand how the members of the Institute use trust as a 'boundary object' (Gieryn, 1983) in the process of institutional mutual orientations, I draw inspiration from the scholarship in science studies on the effect of organizations as meso-level structures which triangulate between scientific domains, national governments, and the industry (Vaughan, 1999; Guston, 1999).

Situating trust in sociology of expertise and social studies of algorithms

Trust is a key component of scientific practice (Shapin, 1994; Porter, 2020 [1995]). And while Anthony Giddens (1990) argued that trust is a defining feature of modernity, we live in an era of increasing mistrust in science (Eyal, 2019; Oreskes, 2019; Nichols, 2017). In the context of science done at the Institute, the question of trust manifests across three overlapping axes: trust between designers and users of new technology, between weather forecasters and AI, and between two epistemic communities (Knorr-Cetina, 1999): weather prediction and computational science. Examining these diverse dimensions of trust calls for synthesizing a few separate strands of debates in the social studies of algorithms.

So, why mistrust AI? The most well-known problem with AI systems is their 'black-boxed' character (Christin, 2020; Pasquale, 2015). The actors depicted in the following pages and researchers in many other domains are attempting to rectify precisely the problem of black boxing by creating 'explainable AI' (Hoffman et al., 2018). Explainability is but one of the examples of emerging conceptions of ethics and trust in AI. In this context, it has become customary for organizations concerned with AI development to publicize their value statements. Many of these frameworks share a core set of principles, or what Greene et al. (2019) called the 'moral background' (Abend, 2014) of AI value statements, which they define as "the grounding assumptions and terms of debate that make conversations around ethics and AI/ML possible in the first place" (Greene et al., 2019: 2122). The question behind this paper is: how does the moral background of AI development shape attempts at articulating situated, use-inspired, and domain-specific value frameworks?

Morality and trust in this context are two independent variables that feed into the same problem: ethics of design. Many authors in critical algorithm and data studies (see Illiadis and Russo, 2016; Moats and Seaver, 2019) have attempted to pin down what ethics both does and should imply (e.g., Richterich, 2018). Some authors have even unpacked the "ethics of ethics of AI" (Hagendorff, 2020; Powers and Ganascia, 2020). Drawing on the discussion about the ethics of algorithms by Mittelstadt and colleagues (2016), I understand the ethics of AI to imply two semi-distinct sets of concerns: epistemic and normative concerns. While the authors observe that "[d]istinct epistemic and normative concerns are often treated as a cluster" (Mittelstadt et al., 2016: 14), I concur that this strategy is analytically disadvantageous because the normative concerns often relate to the public perception and effects of technology, while the epistemic concerns are prioritized by the technology's users and designers. The analytical distinction helps to describe the details of the effects of ethical frameworks.

Mittelstadt et al.'s (2016) typology of standards of AI ethics lists 1) inconclusive evidence, 2) inscrutable evidence, 3) misguided evidence, as epistemic concerns. And 4) unfair outcomes, 5) transformative effects, as normative concerns, with traceability (the ability to determine wherein the process of design an "ethical bug" is embedded) as a technical concerns. In sum, Mittlestadt et al.'s typology gives precise language for inquiries into AI ethics. Nonetheless, I agree with the authors in stating that a "mature 'ethics of algorithms' does not yet exist, in part because 'algorithm' as a concept describes a prohibitively broad range of software and information systems" (Mittelstadt et al., 2016). As this case study shows, the development of ethical standards of AI needs to be grounded in and tailored towards the specific needs of professional communities.

The relationship between trust and ethics begs for more explanation. While both in this paper and in the literature on AI ethics at large, trust and ethics often appear together without much reflection, the actors depicted in the following pages adhere to the view that trust is a key component of an ethical AI. Interestingly, in part, because AI is most often anthropomorphized, the statement that AI should be trusted or trustworthy can be misleading. For example, Mark Ryan argues that "Overall, proponents of AI ethics should abandon the 'trustworthy AI' paradigm (…) replacing it with the reliable AI approach, instead," and adds that it should be the institutions using AI that should be trusted, and not the technology itself (Ryan, 2020: 17). Rather than resolving this definitional tension, my goal is to depict how the actors at the Institute follow similar to proposed by Ryan strategy by constructing a trustworthy and ethical institution in a form of collaborative research methodology closely aligned with the notion of 'AI ethics by design' (d'Aquin et al,, 2018).

Furthermore, the question of trust in AI relates to the problem of automation-led unemployment—one of the key themes in the social studies of algorithms (Benanav, 2020; Besteman and Gusterson, 2019; Eubanks, 2018; Ford, 2015). Much of this discussion centers on the perception of AI as a new and relatively obscure technology that engenders mistrust based on fear among many professionals about being replaced. After all, one could "trust" a technology –in the sense that it will work reliably—and also fear it. In fact, the more reliable the technology, the more one might fear that it will replace people. Resolving this tension is a non-trivial task. For example, Peter McClure (2018) links this 'technophobia' to a general lack of comprehension of the new technologies in a sizable portion of the U.S. population. McClure concludes that technological apprehension is exacerbated by fears of "technological unemployment" (Keynes, 1930; Floridi, 2014). The institute's focus on trust aims to, at the same time, mitigate fears of forecasters about being unemployed and allow them means of engaging with the design process of AI to make technology trustworthy through explainability and adherence to the laws of atmospheric physics.

Mutual orientations

Paul Edwards (1996) introduced the concept of 'mutual orientation' in chapter three of *The Closed World*. Edwards described how an early computer pioneer from MIT, Jay Forrester, convinced the U.S. military of the utility of digital computation to acquire funding for developing a general-purpose computer called "Whirlwind." Forrester's project had to compete with twelve other general-purpose digital computers funded by the Department of Defense. Therefore, Forrester had to present it as more urgent and critical than other early computers. Forrester and his group saw a potential application of their computer to the real-time military control system. Crucially, the focus on real-time control enabled by Whirlwind was the orientation Forrester chose to satisfy the granting agency's needs and compete with the larger pool of digital computer developers. In the words of Paul Edwards, "Forrester's (and MIT's) increasingly grand attempts to imagine military applications for Whirlwind represented expert 'grantsmanship,' or deliberate tailoring of grant proposals to the aims of funding agencies" (Edwards, 1996: 81). But Forrester also informed the funding agency about "as yet undreamt-of possibilities for automated, centralized command and control" (Edwards, 1996: 82). In effect, Forrester framed his research to suit the discourse of command and control, while the military embraced this imaginary as it was partially produced through Forrester's deliberate actions. Forrester's plan was met with strong resistance from the US generals, who saw the idea of being replaced by a computer as unacceptable. It was hence crucial for Forrester to promote trust in his automated technology.

The following analysis shows both mutual orientation between the NSF and the Institute (based on making AI trustworthy) and AI and weather prediction experts (based on making AI explainable and in alignment with the professional intuition of the forecasters). This article captures the following stages in this process: First, a scientific field (in this case, the field of ML) responds to social demands for a new ethical standard for innovation. Second, a network of applied computational researchers seeks collaboration with domain experts, leading to an alternative expertise network. Two kinds of mutual orientations then take place, and furthermore:

a. Mutual orientations between a scientific movement and a funding agency, enabled by a shared ethics of technology development, lead to institutionalization of the movement,
b. The institutionalization leads to the emergence and legitimation of new hybrid forms of expertise.

This theoretical framing intends to make the concept of mutual orientation relevant to the sociology of collaboration and interdisciplinarity (Jacobs and Frickel, 2009) and the social studies of algorithms.

Empirical context: the national strategy for AI development

In September 2020, the NSF announced the creation of six National Artificial Intelligence Research Institutes. Each Institute received $20 million in funding to be dispersed over the next five years. The Institutes were established through the efforts and support of federal agencies (National Science Foundation, U.S. Department of Agriculture, National Institute of Food and Agriculture, U.S. Department of Homeland Security, Science & Technology Directorate, the U.S. Department of Transportation, Federal Highway Administration) and industry partners (Amazon, Google, IBM, Intel, Nvidia, Accenture). Together, the Institutes will form the backbone of the national AI strategy.

Each of the Institutes has a designated theme. The rationale for an institute dedicated to trust has been justified differently by the AI experts and the NSF. While the NSF is invested in promoting a cross-agency framework for the ethical design of AI, the AI experts working with the weather forecasters see the Institute as an opportunity to resolve the jurisdictional struggle stemming in part from the black box problem of algorithmic predictions—predictions which often go against forecasters' intuitions. Dr. Amy McGovern, a computer scientist from the University of Oklahoma, directs the Institute. McGovern leads a team of experts from the fields of ML, atmospheric and ocean science, meteorology, and computer science. The Institute's secondary goal is to forge collaborations between academia, industry, and the private sector.[1]

First mutual orientation: Funding body and an alternative expertise network

The formation of the Institute

The Institute's origins can be traced to a pre-existing expertise network of computer scientists, weather and environmental scientists, and risk communication scholars. The key focus of this scholarly network was research on so-called "use-inspired" (or applied) ML. Institute director Amy McGovern explained that when the NSF released the call for proposals for National AI Institutes, she and her collaborators in meteorology had already begun to conceptualize a plan for a research institute focused on applying AI to atmospheric sciences. Some of the Institute's members have a substantial history of being funded by the National Oceanic and Atmospheric Agency's (NOAA) Joint Technology Transfer Initiative (JTTI). Thanks to this funding, even before the establishment of the Institute, its members dominated the research field in improving the automation of weather prediction.[2] In other words, there was already trust between the Institute's members and the weather prediction community.

Harry Collins et al. (2010) observe that initial trading zones, if successful, often culminate in a shared research proposal. This was the case with the alternative expertise network, arguably with Amy McGovern as one of its leaders. The centerpiece of the proposal was research on trust and AI. The following quote from McGovern illustrates that the AI and weather prediction experts understood the need to establish a common definition of trust:

> We need to work with our targeted set of end-users to learn how they're defining trustworthiness because it seems to be very different [from our definition].

With the release of the call for proposals, the team had to tailor the scope of their work and match definitions to the NSF's vision. While the Institute's focus on trust was prompted by the NSF's desire to establish a center for fundamental research questions on epistemological dimensions of trust in ML, the Institute's mission also became to alleviate the fear of meteorologists of being replaced by AI. The creation of the Institute was an effect of mutual orientation of a bottom-up vision generated by an alternative expertise network (Eyal, 2013) and the top-down framework for "Trustworthy AI" embraced by a federal funding agency, the NSF.

The crucial step in the mutual orientation between the NSF and the alternative expertise network warrants further explanation. While the NSF solicited proposals in the domain of trustworthy AI, the agency did not envision funding research in trustworthy AI, specifically in environmental sciences. The "Trustworthy AI Institute" could as likely focus on biomedicine or any other socially relevant domain. In other words, the NSF chose to orient its vision of future work on trustworthy AI towards a specific expertise network of ML experts already collaborating with weather forecasters and risk communication scholars.[3] As previous research shows, most often, "norms of AI are dynamic and are pieced together from various sources in traditional and transitional ways" (Gasser and Schmitt, 2020: 144). Likewise, the members of the Institute do not simply inherit the categories from the NSF Trustworthy AI framework; rather, they tailor the ethics at the Institute to suit their own experiences as well as the needs of the weather forecasting and the broader environmental science communities. As a result, the trustworthy AI framework became a boundary object, which enabled the initial expertise network to synthesize the definition of the funding agency, domain experts, and their views about what makes algorithmic models reliable.

I ground the discussion of trust in the definition adapted at the Institute from Meyer et al., (1995), which claims that trust is "the willingness to assume risk by relying on or believing in the actions of another party." I further discuss the definition of trustworthiness developed by the NSF.[4]

By making a distinction between a "relational" (involving relationships between actors) character of trust and "evaluative" (emphasizing the process of evaluation of claims, tools, or parties) character of trustworthiness, members of the Institute define "trustworthiness" as "a trustor's evaluation, or perception, of whether, when, why, or to what degree someone or something should or should not be trusted." These two definitions frame the internal work at the Institute.

Altogether, the Institute's work aims to bring together federal, industry, and professional standards of weather forecasting to engender a multidisciplinary workflow on developing trustworthy AI. The key component of overcoming both the fears of automation and mistrust in AI within a new expertise network are three related tasks: incorporating internal to the profession of weather forecasting standards of epistemic reliability, increasing model explainability, and aligning with social and environmental values of earth sciences.

Disrupting the man-machine mix in weather prediction

The institute's drive towards further automation in forecasting has the potential to impact the current dynamic in the long-standing history of the 'man-machine mix' (Henderson, 2017) mix in meteorology. In August 2021, McGovern became Editor-in-Chief of the most recent journal introduced by the American Meteorological Society called *Artificial Intelligence for the Earth Systems*. In a comment about the release of the journal, the president of the AMS, Michael Farrar explained:

> Artificial Intelligence and machine learning offer exciting opportunities to improve our understanding of weather, water, and climate. AMS is excited to host a new journal to improve the science of AI and its applications for AMS-related sciences.

The enthusiasm of the AMS about AI could be explained by the explicit work of the Institute towards establishing trust in the new technology and the legitimation of the novel epistemological model.

The introduction of a new technology into a professional domain engenders both fear and optimism. The enthusiasm of experts such as Michael Farrar about the inclusion of AI experts into their network of expertise—which mirrors the sentiment of many practitioners in the field—fits neatly within two key theoretical concepts originating in the sociological analysis of expertise introduced by Gil Eyal (2013), namely 'generosity' and 'co-production.' Drawing on the actor-network theory, Eyal describes generosity as being "the opposite of monopoly, namely, that a network of expertise, as distinct from the experts, becomes more powerful and influential by virtue of its capacity to craft and package its concepts, its discourse, its modes of seeing, doing, and judging, so they can be grafted onto what others are doing, thus linking them to the network and eliciting their cooperation" (Eyal, 2013: 875).[5] Eyal understands co-production as a process through which "a network of expertise becomes more powerful and influential by virtue of involving multiple parties—including clients and patients—in shaping the aims and development of expert knowledge" (Eyal, 2013: 876). The two concepts are meant to capture how "power consists not in restriction and exclusion, but an extension and linking" (Eyal, 2013: 876). In effect, the generosity and co-production help explain why the weather prediction community perceives AI as part of the strategy for establishing a more powerful expertise network and how AI experts seek to expand their methods into a new, socially relevant problem. In this context, the processes of mutual orientations could be seen as co-production and generosity at work.

"Trustworthy AI" framework and the National Science Foundation

The trustworthy AI framework, as defined by the NSF, bears the mark of its particular intellectual and organizational history. According to the NSF, a trustworthy AI should:

1. Be reliable;
2. Be explainable;
3. Adhere to privacy standards;
4. "Not exhibit biases that are socially harmful."

Using Mittelstadt et al.'s (2016) framework, we can distinguish that while the first two points could be categorized as epistemic concerns, the latter two points refer to normative concerns. This framework has its own history. Jeannette M. Wing[6] (2020) traces the history of conversations about trustworthy computing to the "Trust in Cyberspace" 1999 report by the National Research Council (1999). NSF joined this conversation in 2001 by initiating the Trusted Computing program in 2001 and later by expanding it through the Cyber Trust (2004), Trustworthy Computing (2007), and Secure and Trustworthy Systems (2011) programs (Wing, 2020). Wing observes that the industry soon followed the lead and began producing its own statements, beginning with Bill Gates' 2002 "Trustworthy Computing" memo (Gates, 2002). Some of the early reasons for articulating trust in digital technology had to do with the realization that cyberspace has become, towards the end of the 20th century, a critical national infrastructure prone to both attacks and disasters.[7] Defining what trust in digital infrastructures implies has been an area of discussion and ambiguity since that time. For example, the National Research Council report reads:

> The alert reader will have noted that the volume's title, Trust in Cyberspace, admits two interpretations. This ambiguity was intentional. Parse "trust" as a noun (as in "confidence" or "reliance"), and the title succinctly describes the contents of the volume—technologies that help make networked information systems more trustworthy. Parse "trust" as a verb (as in "to believe"), and the title is an invitation to contemplate a future where networked information systems have become a safe place for conducting parts of our daily lives. Whether "trust" is being parsed as a noun or a verb, more research is key for trust in cyberspace. (National Research Council, 1999: viii).

The subsequent iterations of the definition of trust attempted to ameliorate this ambiguity but also respond to technological developments. Therefore, it is reasonable to expect that the trustworthy AI framework has played a vital role in shaping the mission of one of the NSF's institutes since the Foundation has been deeply invested in defining and promoting the principles of trustworthy computing for over 20 years. Thus, we can see a refinement of a previous ethical statement in accordance with the existing "moral background" of AI development and an increase in the "complexity" of computational systems. The establishment of the Institute hence belongs to the long tradition of redefining trust in digital technology by nation-level actors.

Orienting ethics at the Institute towards NSF's trustworthy framework

The necessity for ethical standards in predictive analytics for environmental science is not a uniformly recognized need. For example, during one of the meetings, McGovern mentioned a pushback against implementing ethical training for environmental science from one of her colleagues from the National Academies of Arts and Sciences:

> I am now on the National Academies Board of atmospheric science and climate, and we're putting together a summer school on AI for Earth System prediction. We had a debate via email this week on whether or not ethics should be a part of that, and I held firm that yes, ethics needed to be part of that. One of the other people on the email chain was holding firm that there was no need for ethics in AI for Earth Science prediction because there was no reason that AI needed to be ethical because there was no bias that would show up. It wasn't that they were advocating that ethics was bad, just that they didn't think that there was any bias in anything that we were doing to predict in Earth Science.

While the ML experts do perceive a need to explore the epistemic grounds of ML predictions, they do not see the normative values as relevant to the application of ML in environmental sciences. Despite this ambivalence, the Institute members agree that the ethics of AI could and should be applied to the design of AI for earth sciences. There are four foundational domains and activities which facilitate a common ethical ground for the Institute. These are 1) reliance on the NSF's trustworthy AI framework, 2) establishment of an Institute-specific code of ethics, 3) formal educational activities—and specifically the core course called "AI, Ethics, and Geoethics" designed and taught by Amy McGovern, 4) discussions of ethical principles during regular, Institute-wide meetings. I will briefly describe each of these activities.

As mentioned above, the NSF Trustworthy AI framework is derived from the principles of trustworthy computing. Drawing on Mittelstadt and colleagues' typology, we see that the framework combines epistemic (reliability, explainability) and normative (privacy, social harm) concerns. However, this framework alone is not specific enough to serve the situated needs of AI in environmental sciences. Therefore, the Institute's code of ethics was derived from the codes of ethics of the American Meteorological Society, the American Geophysical Union, the American Association of Artificial Intelligence, and Google's AI Principles. The confluence of distinct disciplinary and organizational paradigms gave rise to a unique set of ethical considerations. While some of the standards in the Institute's code outline general principles of scholarly conduct, worth mentioning are points 3, 4,5, and 6 of the code (McGovern et al., 2020):

<u>3. Stewardship of the Earth:</u>

1. Members have an ethical obligation to weigh the societal benefits of their research against the costs and risks to human and animal welfare, heritage sites, or other potential impacts on the environment and society.
2. Members also have an ethical obligation to limit their contributions to climate change.

<u>4. Public Communication:</u>

1. Members have an ethical obligation to foster public awareness and understanding of AI, computing, related technologies, and their consequences.

<u>5. When creating AI systems, members will:</u>

1. Ensure that the public good is the central concern during all professional computing work.
2. Give comprehensive and thorough evaluations of AI2ES AI algorithms and their impacts, including analysis of possible risks.
3. Recognize and take special care of AI systems that become integrated into the infrastructure of society.

<u>6. Members will create AI systems that will:</u>

1. Avoid harm.
2. Protect the Earth and its environment including human and animal welfare.
3. Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.
4. Be fair and take action not to discriminate.
5. Respect privacy.
6. Honor confidentiality.
7. Avoid creating or reinforcing bias.
8. Uphold high standards of scientific excellence.

The above principles have guided director McGovern during the design of her course on "Ethics of AI and Geoethics." The course serves both the student body at the University of Oklahoma, the Institute, and is publicly available on the Institute's website. The course reviews topics relevant to AI design, such as bias, transparency, liability, and security, and issues of social responsibility and interdisciplinary dynamics. The emphasis on interdisciplinary communication and collaboration draws on the work of and William Newell and Douglas Luckie (2019) on *Pedagogy for Interdisciplinary Habits of Mind* as well as other seminal works from the field of interdisciplinary studies and the research from the field of team science. McGovern's course poster for the Spring of 2021 prominently features the cover of Ruha Benjamin's book *Race After Technology* (2019), which, as she told me, significantly impacted her.

The language of trust becomes a pidgin (Galison, 1997) through which the Institute operates. Risk communication comes into the picture as the discipline most associated with regulating trust, and hence, they acquire a privileged position in deliberately setting out to comprehend the various definitions of trustworthy AI. Yet, as the forthcoming discussion will show, each group understands trust in a slightly different way. As Collins et al. (2010: 14) suggest, In some cases, interactional expertise trading zones rely on trade managed not by experts from each group who develop an interactional expertise, but rather by third parties who can talk to all groups involved. At the Institute, that risk communication scholars are the "third party" people managing a trade without the necessity for developing of an interactional expertise by other researchers at the Institute. This position is partly enabled by the risk communication scholars' expertise in qualitative methods: as social scientists, they are assumed to know how to translate across epistemic cultures. This translation process is tied to the perception that the language of qualitative social science offers a bird's eye view of the Institute.

One of the goals of the risk communication group (designated as Focus 3: Foundational research in AI risk communication for environmental science hazards) is to "Develop principled methods of using [the group's] knowledge and modeling to inform the development of trustworthy AI approaches and content, and the provision of AI-based information to user groups for improved environmental decision making." This goal is tied to achieving a certain level of pidgin-based communication between various research groups at the Institute. This is done through Institute-coordinated training and communications. Lead risk communication PI Ebert-Uphoff suggested that,

> One way to break down institution and discipline/topics barriers is to have a regular talk series. These talks need to be short and simple at the beginning, so the barrier is relatively low for Institute members to follow, regardless of their research background. Collaboration ideas and actions will most likely develop out of these "101" talks naturally.

What Ebert-Uphoff prescribes for the Institute aligns with Galison's (2010) observation that trade often relies on 'thin interpretation.' According to Peter Galison, "[t]rade focuses on coordinated, local actions, enabled by the thinness of interpretation rather than the thickness of consensus" (Galison, 2010: 36). The Institute-wide meetings often rely on such 'thinness.'

Lastly, the ethics of AI is one of the central topics for the bi-weekly Institute-wide meetings. Worth recounting here was a presentation given by Ebert-Uphoff titled "Responsible Use of AI—What role can [the Institute] play?" One of her slides states, "If the [Institute] does not address Responsible Use of AI for the weather/climate community, who will?" Ebert-Uphoff thus sees the Institute as a "role model" for other communities implementing AI in environmental sciences. The responsible use of AI, according to the author, should include two long-term goals: "Develop new techniques, customized for meteorology," and "Collect and translate existing solutions from [computer science] and other literature." During her presentation, Ebert-Uphoff drew attention to the concept of 'environmental injustice,' a process which she described this way:

> Due to limitations of sensors or other data sources, certain regions or certain meteorological conditions are under-represented in data. ML model learns from data; those scenarios are then under-represented in the ML model as well, which can quickly result in environmental injustice. … Air pollution and other sensors are more prevalent in affluent areas/countries. [and] Southern hemisphere often under-represented.

In response to this point, one of the attendees recounted an anecdote of someone who trained ML model to understand cyclones on data from the North without considering that on the Southern hemisphere, due to the Coriolis effect cyclones spin in the opposite direction. Furthermore, to show that "Using [neural networks] as a black box is not a good idea," in the same talk, Ebert-Uphoff used the story of Clever Hans, a horse who during the early 20th century was believed to have learned arithmetic. Clever Hans, as it turned out, was merely reading the cues of his trainer.[8]

The history of mistrust in automation in weather prediction

The emphasis on trust at the Institute intersects with long-standing tensions between computer modeling and the tacit expertise of weather forecasters—a tension between external and internal forces that came to define meteorology. As the history of weather prediction tells us, fears of automation are hardly new in this profession. This history also demonstrates that automation is not just an inevitable evolution but that it is led by experts from other domains—i.e., computer scientists, data scientists, AI experts.

A term that succinctly captures this professional tension is 'meteorological cancer'. Jennifer Henderson (2017) introduces this term in her ethnography of ethical dimensions of weather prediction. Henderson heard about this term from her interlocutors, who worried that younger forecasters, instead of "developing their own conceptual model" (Henderson, 2017: 1), use almost exclusively computer models to generate their forecasts. As meteorologists with whom Henderson (2017: 1) worked affirm, "[f]orecasters are substituting the computer model for their own knowledge." Henderson shows that the metaphor of 'meteorological cancer' captures the forecasters' realization that by downplaying the importance of their tacit expertise, they "are contributing to their own demise" (Henderson, 2017: 1). As with other professions, forecasters have for a long time been aware of their own, often elusive, position within the 'man-machine mix' (Henderson, 2017). Part of Henderson's (2017: 3) ethnographic goal was to understand the "competition of forecasters rivaling computer models for daily work even as the machines increasingly outperform them". This ethnographic account thus shows in detail how the fear of being automated out of a job manifests. Yet, the 'ontological fears' of weather forecasters, as Henderson calls them, are "not so much the loss of labor but the change in the image of themselves" (Henderson, 2017: 46).

The advent of modern weather forecasting is marked by the development of Numerical Weather Prediction (NWP) in the 1930s and 40s and the employment of computers to model atmospheric data. In Kristine Harper's words, the meteorologists sought to invest their energy and resources in developing NWP "to increase the fortunes of a research community that had long been on the margins of U.S. science" and, consequently, "to replace the art of forecasting with the science of meteorology" (Harper, 2012: 668). The meteorologists' goal, Harper (2012) argues, was to elevate meteorology to the status of a 'legitimate' and objective scientific discipline by increasing the quantitative element of the field.

Harper (2012) observes that there are two parallel views within the historiography of meteorology about who was more instrumental in shaping the field. One part of this literature emphasizes external actors, such as the polymath John von Neuman, who was deeply involved in designing the first computing system for weather forecasting. At the same time, other scholars attribute more substantial agentive capacity to meteorologists in defining their future. This argument aside, the point is that the birth of modern weather prediction is tied to the shift in the network of expertise in meteorology: NWP, in Harper's account, has been made possible by the "availability of a new and larger pool of scientifically educated and mathematically savvy meteorologists" (Harper, 2012: 670-71). Considering this history, I suggest that the mistrust of AI may result from not only a fear of 'technological unemployment' but also of destabilization of a professional identity. Furthermore, there is nothing new about the mistrust of automation, but the method of addressing it—by creating an intermediary professional organization—is a novel development.

As such, meteorology is one among a growing number of professions that face existential angst due to advancements in AI. Sociologist Phaedra Daipha (2015: 106) understands weather forecasting "as the art of collage" By this, Daipha means that weather forecasting is characterized by the "art of improvisation," or an ability to mobilize various streams of data and modeling and be competent in screenwork analysis, as well as actual observation of physical weather. Following Daipha and other ethnographers of weather professionals, I frame the introduction of AI into the field as part of the larger 'collage,' or "a heuristic that frames meteorological decision-making as a process of assembling, appropriating, superimposing, juxtaposing, and blurring of information" (Daipha, 2015: 21). Daipha further describes weather forecasting as 'art and science,' and foregrounds the blurring of the boundaries between human and the machine in the profession. In another register, what takes place at the Institute is a jurisdictional struggle between groups of experts who embrace 'mechanical objectivity' on the one hand and 'trained judgment' (Daston and Galison, 2010) on the other.

Second mutual orientation: Weather forecasters and machine learning experts

The introduction of AI in weather forecasting is a story of ethical and epistemological progression towards ever-increasing speed and accuracy of predictions. But what will make AI-based predictions more trustworthy? And "Who possesses the better understanding of the atmosphere: those who crunch the numbers, but never look outside, or those who are unimpressed by equations, but read the sky?" (Henderson, 2017: 689). Forecasters have asked this question for almost 70 years. In the story of Jay Forrester and the Whirlwind, Paul Edwards (1996) notes that it was Forrester who deliberately influenced high-ranking officials in the Office of the Naval Research, who initially were skeptical of the utility of the digital computer. Some generals were hostile to the idea that a machine could perform the tacit knowledge of strategizing. Analogously, the weather forecasting community has been characterized by friction between those who 'read the sky' and those who 'crunch the numbers,' to use Harper's (2012) words.

To gain the community's trust and secure a mutual orientation between ML and weather forecasting experts, the members of the Institute had to learn to do both. The ML experts at the Institute have understood the need to design ML that weather forecasters could trust. This form of ML is based on two central properties: explainability and adherence to the laws of physics. In sum, ML experts realized that to get the forecasters to trust their system, they needed AI to satisfy a number of criteria: 1) be explainable, 2) adhere to the laws of physics and look 'realistic,'[9] 4) adhere to the tacit norm of "erring on the side of caution." The following subsection examines these related criteria in AI design.

Trustworthy AI needs to be both explainable and realistic

McGovern has a long history of spanning the boundaries of computer science and weather forecasting. As a result, she has a unique vantage point to understand the role of explainability as a crucial factor in promoting ML for weather forecasting. McGovern's doctoral work was in computer science and on a type of AI called reinforcement learning (RL). At the University of Oklahoma, she holds a full professorship in both the School of Computer Science and the School of Meteorology. With expertise in ML and weather forecasting, she is a boundary-spanning figure (Aldrich and Herker, 1977; Ribes et al., 2019) who strives to present ML methods in ways the meteorology community can understand and trust. In a paper titled "Making the Black Box More Transparent: Understanding the Physical Implications of ML" (McGovern et al., 2019) published in *the Bulletin of the American Meteorological Society*, McGovern and colleagues argued:

> Despite its wide adoption in meteorology, ML is often criticized by forecasters and other end users as being a "black box" because of the perceived inability to understand how ML makes its predictions. This phenomenon is not exclusive to meteorology, and many ML practitioners and users have recently begun to focus on this interpretability problem (McGovern et al., 2019: 2176).

This problem statement made by a computer scientist in a prime venue for meteorological research attests to the gravity of the problem of trust in automation in weather forecasting.

But professional meteorologists are not the only group the Institute's members seek trust from. In one of the talks about the Institute presented at the "2nd Workshop on Leveraging AI in Environmental Sciences" organized by NOAA, McGovern said: "You can't develop one particular AI technique that's going to meet all of these needs. What you need to do is to take into account the end user's needs and to make it trustworthy for that end user—you need to care about the end-user that you're looking at." This approach to trustworthiness requires deliberate tailoring of both algorithmic tools and discourses that explain these tools to different publics and actors.

According to the Institute members, the key to solving the problem of trust in AI among both the forecasters and the public is explainability. In one of the lectures she delivered about the Institute, McGovern described the mission of the Institute in the following manner:

> we're working on developing explainable AI methods that are aligned with environmental science, domain perspectives and priorities. This means that we care about what environmental scientists care about. We care about the spatial and temporal nature of the data. We care about the physics-based nature of the data, etcetera. So, it isn't just an explainable AI method that's developed theoretically—we're testing it on all the environmental science domains.

During one of the Institute meetings, McGovern stated succinctly:

> what is the future of everything we are trying to do? I think we need to integrate the AI and the physics and the robust approaches that we've started with explainable AI.

McGovern and her team are devoted to a solution-oriented approach grounded in problems emerging from environmental sciences. For the Institute members, specificity matters—the spatial, temporal, and physical aspects of environmental data, as well as the needs of potential users, need to be considered. As one researcher at the Institute said, "If we're going to be showing the results of these [predictive models] to [forecasters] to say: 'this is trustworthy,' you can't give them stuff that doesn't look realistic at all."

Not all AI models have laws of physics built into them. And for weather forecasters, physics-based AI is one of the conditions for the technology's reliability and realism. "Physics-based AI" is a family of AI models that respects actual physical processes, such as the dynamics of storm formation. Making ML models physics-based is part of the process of establishing trust in the model, specifically in the domain of weather forecasting. In effect, the ML experts themselves have to develop an understanding of the physics of weather. This is one of the most challenging things to train as an ML expert. Forecasters need translators who can explain how algorithms arrive at their results. While prior to the establishment of the Institute, this translation had to be managed solely between AI and weather experts, the Institute adds an extra layer of risk communication scholars who, through their social science sensitivity, can help mediate across epistemic cultures (Knorr-Cetina, 1999).

In this context of interdisciplinary translation work, I want to draw attention to the complexity of 'opening the black box' of algorithms as a solution to the problem of trust. As Anthony Giddens argued,

> There would be no need to trust anyone whose activities were continually visible and whose thought processes were transparent or to trust any system whose workings were wholly known and understood. (Giddens, 1990: 33)

Following Giddens, we can conclude that full explainability would ostensibly make the articulation of standards of trust obsolete. But full explainability is rarely attainable. Trust requires more than just explainability.

Analyses of explainability and transparency have been a key trope among critical algorithmic and data studies scholars, some of whom have observed limitations of the notion of transparency. For example, Mike Ananny and Kate Crawford (2018: 5) observe that transparency "assumes that knowing is possible by seeing, and that seemingly objective computational technologies like algorithms enact and can be held accountable to a correspondence theory of truth". But as Ananny and Crawford make apparent, transparency does not necessarily build trust. On the other hand, Cynthia Rudin and Joanna Radin (2019) questioned whether we need to make 'black-boxed' AI in the first place. They argued that "an accurate machine or an understandable human" (Rudin and Radin, 2019: 4) is a false dichotomy. The explainability of AI systems is undeniably a virtue that researchers strive for, but as Rudin and Radin point out, the dichotomy between "Being asked to choose an accurate machine or an understandable human is a false dichotomy" (Rudin and Radin, 2019: 4). While arguably the philosophy of technology at the Institute reproduces this dichotomy, the question remains how the Institute will help to resolve this tension, and how explainability will influence the uptake of AI in weather prediction.

When machine learning goes out to lunch and predicts the end of the world: Calibration and mutual orientations at the NOAA's Storm Prediction Center

The fundamental conundrum in the forecaster's work is to determine whether to trust automated prediction generated by a computer or their own intuitions. The mode of prediction in ML clashes with institutional norms and forecasters' intuitions. As Henderson (2017) notes, a part of forecasters' trust is based on reducing their exposure to criticism by 'under forecasting'—meaning here simply to communicate to the public lower probabilities than those generated by their mental and digital models. Yet, ML models do not hold to this facet of an 'ethic of accuracy' of weather prediction (Henderson, 2017; see also MacKenzie, 1987). Paramount in this context is the importance of "calibration" between forecasters' predictions and the predictions of ML models, which, while not as accurate in the eyes of ML experts as it could be, respects the implicit norms of weather forecasters. By calibration, here I mean a process of translating ML models into more realistic forms of prediction. The next few paragraphs offer an example of a tension between ML researchers who try to be as accurate as possible and forecasters who lean towards performing cautious predictions.

During one of the Institute meetings, director McGovern recollected an event during which a model deemed efficient by the ML experts was considered to be untrustworthy by the NOAA's Storm Prediction Center (SPC) forecasters. The point of contention was a divergence between the ML models' and the forecasters' predictions. One Institute member explained: "on this particular day, the ML model gave 80% [probability] of a certain temperature, while the SPC issued the probability of 50%." Critically, due to the tacitly accepted principle of "erring on the side of caution" (Henderson, 2017: xxxvi), the highest probability forecasters wanted to issue was 60%.[10] McGovern elaborated: "From our perspective, a 100% probability wasn't a problem (…) if the model says a 100, why shouldn't we say a 100? But the SPC said 'hell no.'" Another ML expert remarked: "You can see that by design, SPC wants to under-forecast." The same expert put this divergence in the context of their long-term work with the SPC:

> You're trying to defend the model the first year. And [the SPC people] would just flip past because it's like: 'Oh yeah, the ML is out to lunch again, it's putting 80%.' (…) So, when they're looking at 30% as a high-end event, and a model is putting out 85%, they're looking at it and saying, 'Oh, this model is basically predicting the apocalypse for every day, and we can't trust it if it's always predicting the end of the world.'

The forecasters could not trust the ML models because they suggested probabilities much higher than they were used to. But, as this particular ML researcher explained, "By default, the model doesn't have any sort of idea of what SPC predicts. It just gives you a raw weighting based on (…) the data." To remedy this divergence, designing physics-based AI and calibration of models has emerged as a critical issue. The concept of calibration in this scenario becomes one of the modes of a mutual orientation between two groups of experts. To make AI probabilities align more with forecasters' norms, AI researchers calibrated the model which previously "has gone to lunch" with multiple real-life datasets. Only after the appropriate calibration took place were the forecasters' and models' predictions aligned.

This scenario exemplifies a classical problem of expert system approach to AI and the long-standing tension between predictive experts and computers. One of the solutions to the calibration problem in the eyes of the Institute members is to extract 'mental models' of forecasting and input them into ML predictions. Imme Ebert-Uphoff mentioned that it would be beneficial to use social science methods to understand how forecasters read the data and build AI based on those 'mental models.' She emphasized "getting feedback from social scientists about how we should develop ML methods" and explained that she does "a little bit of interviewing" when she sits down with an end-user and asks: "how do you do [predictive work] right now?" In her experience, forecasters often clash with the computer science people who say, "let the computer do it all." In one of the talks, she concludes:

> We could do the whole community a big favor by revisiting the entire topic—not just what explanations should be like, but can we make

> ML a little bit more like what people do manually right now? (…) Can we build a mechanism and vocabulary where we can actually talk about it?

A fascinating aspect of this situated process of calibration is that despite a historical decline in the prominence of the expert system approach to AI development, the ethics of explainability pushes some AI developers to once again revisit this less prominent form of AI[11] In recent years, it was the data-driven system that won the battle, but the Institute is evincing the prowess of the expert systems approach.

Discussion

This case study testifies to the necessity of supplementing contemporary critique of AI with historical analysis. Initiatives like the Cambridge University seminar series on "Histories of Artificial Intelligence: A Genealogy of Power" are among many scholarly developments promoting an integrative, historical, and sociological examination of AI. From such a vantage point, the introduction of AI into weather forecasting can be better understood within the context of a *longue durée* of the interplay between trained judgment and mechanical objectivity in weather prediction (Daston and Galison, 2010). For example, Henderson argues that the crux of the matter is that:

> Amid the talk of competition between humans and their technologies, then emerges a tension between the success of their work as predictive experts, which computer models help facilitate, and the value of their own expert skill in the process. At stake are the identities of forecasters as scientists and the survival of their profession in ways they envision it ought to exist (Henderson, 2017: 10)

She adds: "In a forecasting office, boundaries between human and computer are fluid, blurred, and multiple. There is no single human nor a solitary machine but a plurality of both" (Henderson, 2017: 10). As with other professions, AI might merely reposition the boundaries between the human and the computer. Nonetheless, such repositioning can turn into a professional 'identity crisis' (Henderson, 2017: 11). The possible disruption in the professional identity of forecasters caused by AI lies at the core of the jurisdictional struggle explored in this paper. Interpreting such emerging jurisdictional struggles with attention to the history of automation might prove to be analytically advantageous for STS scholars, as well as for technology designers and policymakers.

The establishment of the Institute suggests that the introduction of AI into domains such as weather forecasting and environmental sciences at large necessitates deliberate training in novel, hybrid forms of expertise. The need for calibration between the professional norm of "under forecasting" and AI's predictions also illustrates the tacit dimensions of professional expertise. This state of affairs is present in other professional contexts as well. For example, an ethnographic study of predictive policing revealed the importance of forming new intermediary occupational roles as a key to securing trust in AI (Waardenburg et al., 2018). Such professional intermediaries helped to establish "the superiority of algorithmic decisions over human expertise," but their presence also "further black-box[ed] the inherent inclusion of human expertise" in making decisions based on AI reccomendations (Waardenburg et al., 2018: 14). The capacity to interpret 'black-boxes' comes with a specific form of intellectual capital. Those possessing such expertise might likely succeed in gaining prominence within the larger domain. Therefore, the introduction of professional intermediaries might have profound effects on the future of environmental prediction.

Relatedly, as a growing literature focused on environmental data practices alerts us to the unique characteristics of environmental data (e.g., Fortun et al., 2016; Gabrys, 2016, 2020; Lippert, 2015), critical algorithm and data scholars will need to pay more attention to the formulation of AI and data ethics in environmental sciences. Recounted above debate among the Institute members about whether AI in Earth Sciences might exhibit biases is a case in point. To repeat, as McGovern put it, one of her collegues argued that "there was no need for ethics in AI for Earth Science prediction because there was no reason that AI needed to be ethical because there was no bias that would show up." Arguably, environmental STS analysis can offer a more nuanced and situated view of algorithmic bias and ethics at large. Interdisciplinary communication across social, environmental, and computer sciences is becoming more ubiquitous in AI design, and the Institute might offer many best practices for such collaborations. On the STS side, many scholars have adopted an openly collaborative ethos, as for example in Gina Neff and collegues' "practice-based framework for imporving critical data studies and data science" (Neff et al., 2017: 85), and such frameworks might also prove generative for studies of both data and algorithms and for fostering interdisciplinary dialogue.

The study of the orientations of scientific research toward socially relevant problems has produced many insights into the formation of new scientific movements and disciplines (Frickel, 2004; Jacobs, 2014; Hess et al., 2008). Nevertheless, there is a pressing need for further research about the role the ethics of technology design plays in the formation of networks of expertise consisting of private, public, and academic actors. Ethics statements common to industry often have objectives distinct from those embraced by public agencies or universities, and how the many genres of ethical frameworks are consolidated will require further study. Multi-sector collaborations engender the composition of unique and discipline-tailored ethical standards, thus putting into question the utility of "one size fits all" design standards.

Multi-sector organizations might prove to be very effective spaces for translating hig level policy discourses and moral backgrounds of technology development for the purpose of discipline-specific use of AI. Paul Edwards (1996) argued that the funding of Forrester's Whirlwind project—a project that paved the way for semi-automatic command and control systems in the army to the dismay of many high-ranking officials—could not be possible outside of the political milieu of the late 1940s and early 1950s. Analogously, the contemporary cultural conversation and policy discourses about the ethics of AI were a causal factor in instigating a mutual orientation between the NSF, the Institute, and weather forecasters. But the middle ground between policy discourses and technology development is often occopuied by boundary organizations (Guston, 1999; Vaughan, 1999). More research is necessary to capture how situated and idiosyncratic standards of AI design become stabilized and embraced by muti-sector projects and organizations, especially as more private-public partnerships (such as US NSF AI Institutes) are created under the often-seemingly over-arching umbrella of national AI strategies.

Conclusions

The evincing of ethical and socially desirable image plays a significant role during the emergence and institutionalization of alternative expertise networks. This is often done, as in the case of the Institute, through an alignment with pre-existing ethical standards or moral backgrounds (Abend, 2014) of technology design, but it also involves extensive, domain-specific adjustment of standards. This study intervenes in the literature on the ethics of AI by showing that the prevailing moral background and national ethical standards of technology development, while crucial, are by themselves insufficient in providing tailored solutions to domain-specific issues associated with trust in new technologies. The use of the concept of 'mutual orientations' and the reading of the literature on the sociology of expertise and SCOT approach offers an analytical purchase on the question of how alignments of design standards shape emerging expertise networks and the introduction of AI into an existing predictive science. Moreover, the concept of 'mutual orientations' highlights the dynamic nature of the institutionalization of hybrid expertise networks. Indeed, introducing new technology into a professional field is often led by a desire to form a more robust network through generosity and co-production (Eyal, 2013). The above analysis highlights the importance of not only the role of transparency in forging trust between experts but also of a design process sensitive to the norms and standards of an expert community. For the experts at the Institute, this meant creating algorithms that adhered to the laws of physics and intuitions and norms of weather forecasters.

References

Abbott A (2014) *The System of Professions: An Essay on the Division of Expert Labor*. Chicago: University of Chicago press.

Abend G (2014) *The Moral Background*. New Jersey: Princeton University Press.

Aldrich H and Herker D (1977) Boundary Spanning Roles and Organization Structure. *Academy of Management Review* 2(2): 217–230.

Ananny M and Crawford K (2018) Seeing without Knowing: Limitations of the Transparency Ideal and Its Application to Algorithmic Accountability. *New Media & Society* 20(3): 973–989.

Benanav A (2020) *Automation and the Future of Work*. London: Verso.

Benjamin R (2019) *Race After Technology: Abolitionist Tools for the New Jim Code*. Hoboken: John Wiley & Sons.

Besteman C and Gusterson H (2019) *Life by Algorithms: How Roboprocesses Are Remaking Our World*. Chicago: University of Chicago Press.

Bijker W E (1997) *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambrdige: MIT Press.

Brady J (2018) Toward a Critical, Feminist Sociology of Expertise. *Journal of Professions and Organization* 5(2): 123–38.

Brysse K, Oreskes N, O'reilly J and Oppenheimer M (2013) Climate change prediction: Erring on the side of least drama? *Global Environmental Change* 23(1): 327-337.

Callon M (1984) Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay. *The Sociological Review* 32(1_suppl): 196–233.

Christin A (2020) The Ethnographer and the Algorithm: Beyond the Black Box. *Theory and Society* 49(5): 897–918.

Collins H, Evans R and Gorman M (2007) Trading Zones and Interactional Expertise. *Studies in History and Philosophy of Science Part A* 38(4): 657–666.

Collins H, Evans R and Gorman M (2010) Trading Zones and Interactional Expertise. In: Gorman M (ed) *Trading Zones and Interactional Expertise: Creating New Kinds of Collaboration*. Cambridge: MIT Press, pp.7-24.

Crawford K (2021) *The Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence*. New Haven: Yale University Press.

Daipha P (2015) *Masters of Uncertainty*. Chicago: University of Chicago Press.

Daston L and Galison P (2010) *Objectivity*. New Jersey: Princeton University Press.

d'Aquin M, Troullinou P, O'Connor N E, Cullen A, Faller G and Holden L (2018) Towards an ethics by design methodology for AI research projects. In: *Proceedings of the 2018 AAAI/ACM Conference on AI, Ethics, and Society*, pp. 54-59.

Dick S (2019) Artificial Intelligence. *Harvard Data Science Review* 1(1).

Dubber M D, Pasquale F and Das S (2020) *The Oxford Handbook of Ethics of AI*. Oxford: Oxford Handbooks.

Edwards P N (1996) *The Closed World: Computers and the Politics of Discourse in Cold War America*. Cambridge: MIT Press.

Epstein S (1995) The Construction of Lay Expertise: AIDS Activism and the Forging of Credibility in the Reform of Clinical Trials. *Science, Technology, & Human Values* 20(4): 408–37.

Epstein S (2008) *Inclusion: The Politics of Difference in Medical Research*. Chicago: University of Chicago Press.

Eubanks V (2018) *Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor*. New York: St. Martin's Press.

Eyal G (2013) For a Sociology of Expertise: The Social Origins of the Autism Epidemic. *American Journal of Sociology* 118(4): 863–907.

Fleagle RG (1986) NOAA's Role and the National Interest. *Science, Technology, & Human Values* 11(2): 51–62.

Floridi L (2014) Technological Unemployment, Leisure Occupation, and the Human Project. *Philosophy & Technology* 27(2): 143–50.

Ford M (2015) The Rise of the Robots: Technology and the Threat of Mass Unemployment. *International Journal of HRD Practice Policy and Research* 111.

Fortun K, Poirier L, Morgan A, Costelloe-Kuehn B and Fortun M (2016) Pushback: Critical Data Designers and Pollution Politics. *Big Data & Society* 3(2): 2053951716668903.

Frickel S (2004) *Chemical Consequences: Environmental Mutagens, Scientist Activism, and the Rise of Genetic Toxicology*. New Brunswick: Rutgers University Press.

Frickel S and Gross N (2005) A General Theory of Scientific/Intellectual Movements. *American Sociological Review* 70(2): 204–232.

Gabrys J (2016) Practicing, Materialising and Contesting Environmental Data. *Big Data & Society* 3(2): 2053951716673391.

Gabrys J (2020) Smart Forests and Data Practices: From the Internet of Trees to Planetary Governance. *Big Data & Society* 7(1): 2053951720904871.

Galison P (1997) *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press.

Galison P (2010) Trading with the enemy. *Trading zones and interactional expertise: Creating new kinds of collaboration* 21(1): 147-175.

Gasser U and Schmitt C (2020) The Role of Professional Norms in the Governance of Artificial Intelligence. In: Dubber M D, Pasquale, F and Das S (eds) *The Oxford Handbook of Ethics of AI*. Oxford: Oxford University Press, pp. 141-162.

Gates B (2002) Trustworthy Computing Memo. Available at: https://news.hitb.org/content/complete-text-bill-gates-trustworthy-computing-memo (accessed 8.1.2023).

Giddens A (1990) *The Consequences of Modernity*. Redwood City: Stanford University Press.

Gieryn T F (1983) Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists. *American Sociological Review* 48(6): 781–795.

Greene D, Hoffmann A L and Stark L (2019) Better, Nicer, Clearer, Fairer: A Critical Assessment of the Movement for Ethical Artificial Intelligence and Machine Learning. In: *Proceedings of the 52nd Hawaii international conference on system sciences*.

Guston D H (1999) Stabilizing the Boundary between US Politics and Science: The Role of the Office of Technology Transfer as a Boundary Organization. *Social Studies of Science* 29(1): 87–111.

Hagendorff T (2020) The Ethics of AI Ethics: An Evaluation of Guidelines. *Minds and Machines* 30(1): 99–120.

Harper K C (2012) *Weather by the Numbers: The Genesis of Modern Meteorology*. Cambrdige: MIT Press.

Henderson J J (2017) To Err on the Side of Caution: Ethical Dimensions of the National Weather Service Warning Process. Dissertation. Virginia Tech.

Hess D, Breyman S, Campbell N and Martin B (2008) Science, Technology, and Social Movements. In: Hackett E J, Amsterdamska O, Lynch ME and Wajcman J (eds) *The Handbook of Science and Technology Studies.* Cambridge: MIT Press, pp. 473-498.

Hoffman R R, Mueller S T, Klein G and Litman J (2018) Metrics for Explainable AI: Challenges and Prospects. *ArXiv Preprint ArXiv:1812.04608*.

Iliadis A and Russo F (2016) Critical Data Studies: An Introduction. *Big Data & Society* 3(2): 2053951716674238.

Jacobs J A and Frickel S (2009) Interdisciplinarity: A critical assessment. *Annual review of Sociology* 35: 43–65.

Jacobs J A (2014) *In Defense of Disciplines*. Chicago: University of Chicago Press.

Keynes J M (1930) Economic Possibilities for Our Grandchildren; Scanned by Yale University Economics Department from John Maynard Keynes, Essays in Persuasion. New York: Norton.

Kitchin R (2014) Big Data, New Epistemologies and Paradigm Shifts. *Big Data & Society* 1(1): 2053951714528481.

Kline R R (2015) *The Cybernetics Moment: Or Why We Call Our Age the Information Age*. Baltimore: Johns Hopkins University Press.

Knorr-Cetina K (1999) *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge: Harvard University Press.

Lippert I (2015) Environment as Datascape: Enacting Emission Realities in Corporate Carbon Accounting. *Geoforum* 66: 126–35.

Lipton Z C and Steinhardt J (2018) Troubling Trends in Machine Learning Scholarship. *ArXiv Preprint ArXiv:1807.03341*.

MacKenzie D (1987) Missile Accuracy: A Case Study in the Social Processes of Technological Change. In: Bijker W E, Hughes T P and Pinch T (eds) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology.* Cambridge: MIT Press, pp. 195–222.

Mannheim K (2013) *Ideology and Utopia*. London: Routledge.

McClure P K (2018) "You're Fired,' Says the Robot: The Rise of Automation in the Workplace, Technophobes, and Fears of Unemployment.' *Social Science Computer Review* 36(2): 139–56.

McGovern A, Lagerquist A, Gagne R et al. (2019) Making the Black Box More Transparent: Understanding the Physical Implications of Machine Learning. *Bulletin of the American Meteorological Society* 100(11): 2175–99.

McGovern A, Neeman H, Hickey J and Gagne D J (2020) AI2ES Strategic and Implementation Plan. Available at: https://docs.google.com/presentation/d/15Xu2Ze1EBA0T3KESOEQeXL4ZRX66Y7xMocpJs2XHcSw/edit#slide=id.p (accessed: 01.07.2024).

Mendon-Plasek A (2021) Mechanized Significance and Machine Learning: Why It Became Thinkable and Preferable to Teach Machines to Judge the World. In: Roberge J and Castelle M (eds) *The Cultural Life of Machine Learning*. Heidelberg: Springer, pp. 31-78.

Metcalf J and Moss E (2019) Owning Ethics: Corporate Logics, Silicon Valley, and the Institutionalization of Ethics. *Social Research: An International Quarterly* 86(2): 449–76.

Mittelstadt B D, Allo P, Taddeo M, Wachter S and Floridi L (2016) The Ethics of Algorithms: Mapping the Debate. *Big Data & Society* 3(2): 2053951716679679

Moats D and Seaver N (2019) 'You Social Scientists Love Mind Games': Experimenting in the 'Divide' between Data Science and Critical Algorithm Studies. *Big Data & Society* 6(1): 2053951719833404.

National Academy of Engineering, U. S. (2004) *The Engineer of 2020: Visions of Engineering in the New Century*. Washington: National Academies Press.

National Research Council (1999) *Trust in Cyberspace*. Edited by Schneider FB, Washington: The National Academies Press.

Neff G, Tanweer A, Fiore-Gartland B and Osburn L (2017) Critique and contribute: A practice-based framework for improving critical data studies and data science. *Big data* 5(2): 85-97.

Newell W H and Luckie D B (2019) Pedagogy for Interdisciplinary Habits of Mind. *Journal of Interdisciplinary Studies in Education* 8(1): 6–20.

Nichols T (2017) *The Death of Expertise: The Campaign against Established Knowledge and Why It Matters*. Oxford: Oxford University Press.

Olhede S C and Wolfe P J (2018) The Growing Ubiquity of Algorithms in Society: Implications, Impacts and Innovations. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 376(2128).

O'Mahony S and Bechky B A (2008) Boundary Organizations: Enabling Collaboration among Unexpected Allies. *Administrative Science Quarterly* 53(3): 422–459.

Oreskes N (2019) *Why Trust Science?* New Jersey: Princeton University Press.

Oui J (2022) Commodifying a "good" weather data: commercial meteorology, low-cost stations, and the global scientific infrastructure. *Science, Technology, & Human Values* 47(1): 29-52.

Pasquale F (2015) *The Black Box Society*. Cambridge: Harvard University Press.

Pasquale F (2019) A Rule of Persons, Not Machines: The Limits of Legal Automation. *George Washington Law Review* 87(1).

Pinch T J and Bijker W E (1984) The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social studies of science* 14(3): 399–441.

Polanyi M (2009) *The Tacit Dimension*. Chicago: The University of Chicago Press.

Porter T M (2020) *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. New Jersey: Princeton University Press.

Powers T and Ganascia J-G (2020) *The Ethics of the Ethics of AI*. Oxford: Oxford University Press.

Randalls S (2010) Weather Profits: Weather Derivatives and the Commercialization of Meteorology. *Social Studies of Science* 40(5): 705–730.

Rabeharisoa V and Callon M (2002) The involvement of patients' associations in research. *International Social Science Journal* 54(171): 57–63.

Randalls S (2017) *Commercializing Environmental Data: Seeing like a Market.* London: Routledge.

Ryan M (2020) In AI we trust: ethics, artificial intelligence, and reliability. *Science and Engineering Ethics* 26(5): 2749–2767.

Ribes D, Hoffman A S, Slota S C and Bowker G C (2019) The Logic of Domains. *Social Studies of Science* 49(3): 281–309.

Richterich A (2018) *The Big Data Agenda: Data Ethics and Critical Data Studies*. London: University of Westminster Press.

Rottner R (2019) Working at the Boundary: Making Space for Innovation in a NASA Megaproject. *Social Studies of Science* 49(3): 403–431.

Rudin C and Radin J (2019) Why Are We Using Black Box Models in AI When We Don't Need to? A Lesson from an Explainable AI Competition. *Harvard Data Science Review* 1(2).

Shapin S (1994) *A Social History of Truth: Civility and science in seventeenth-century England*. Chicago: University of Chicago press.

Shapin S (2008) *The Scientific Life: A Moral History of a Late Modern Vocation*. Chicago: University of Chicago Press.

Slayton R and Clarke B (2020) Trusting Infrastructure: The Emergence of Computer Security Incident Response, 1989–2005. *Technology and Culture* 61(1): 173–206.

Star S L and Griesemer J R (1989) Institutional Ecology, Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science* 19(3): 387–420.

Vaughan D (1999) The Role of the Organization in the Production of Techno-Scientific Knowledge. *Social Studies of Science* 29(6): 913–943.

Waardenburg L, Sergeeva A and Huysman M (2018) Hotspots and Blind Spots. In: *Working Conference on Information Systems and Organizations*. Heidelberg: Springer, pp. 96-109.

Waidzunas T (2013) Intellectual Opportunity Structures and Science-Targeted Activism: Influence of the Ex-Gay Movement on the Science of Sexual Orientation. *Mobilization: An International Quarterly* 18(1): 1–18.

Wing J M (2020) Trustworthy Ai. *ArXiv Preprint ArXiv:2002.06276*.

Notes

1 On the commercialization of meteorology and weather data, see Randalls, 2010, 2017; and Oui, 2022; and on the effects of the business-oriented model on the history of NOAA, see Fleagle, 1986.

2 For an analogous analysis of a relationship between politics and science, see Guston's (1999) work on the Office of Technology Transfer as a 'boundary organization.'

3 Boundary organizations, like the Institute, often bring unexpected collaborators together (O'Mahony and Bechky, 2008).

4 Trust has been defined differently in other institutional (i.e., Mozilla Foundation) and political (European Union) contexts (see Greene et al., 2019).

5 Eyal borrows the concept of co-production not directly from the seminal work of Sheila Jasanoff but from Vololona Rabeharisoa and Michel Callon's (2002) reading of Jasanoff.

6 Wing, who is now the director of the Data Science Institute at Columbia University, has been deeply involved in shaping the NSF's perspective on trust as an Assistant Director of the Computer and Information Science and Engineering Directorate between 2007 and 2010.

7 For the historical context about trust and computing infrastructure, see Slayton and Clarke, 2020.

8 See Kate Crawford (2021: 4) on the myth of Clever Hans.

9 'Realistic,' a term forecasters use, means in this context that ML models need to respect the laws of physics. Making ML models physics-based is, hence, part of the process of establishing trust in the model.

10 Brysse et al. (2013) observed a similar bias towards 'erring on the side of least drama' among climate scientists who, contrary to some accusations of alarmism, often underpredict future climate change.

11 For the history of the relationship between expert systems and data-driven approaches in ML, see Dick, 2019 and Mendon-Plasek, 2021.

When Numbers Run Out: Civil Registration and the Performativity of Methods

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Abstract

In the early 2000s, authorities in Sweden and Denmark recognised that their personal identification numbers were about to run out but followed different interventions to resolve the same issue. In this paper, I start from these cases to analyse personal identification numbers as methods for knowing and governing populations. I draw on two assertions from the study of methods within STS: Methods are performative, and they produce multiple objects and realities. I demonstrate how such identification numbers enact individuals and populations simultaneously, and I identify a fundamental tension between them: one emphasising the representational potential of the part and another favouring the coherence of the whole. I conclude that issues surrounding personal identification numbers in use across all Nordic countries can be traced back to a fundamental tension in addressing individuals that is impossible to resolve via technical modifications, although those interventions are crucial for keeping the systems operational.

Keywords: Identification, Numbers, Civil Registration, Methods, Performativity.

Introduction

In 2009, the Swedish government recognised that they were about to run out of numbers. The *personnummer* (personal identification number), originally introduced in 1947 and currently used in nearly all citizen-state interactions, was nearing capacity and would soon be unable to represent people born on certain dates. The problem was connected to the inclusion of the date of birth in the number itself: because some dates of birth were overrepresented in the Swedish population, soon there would be no more space left to register new people.

On 29 January 2009, the government proposed a change in the civil registration law to the parliament (SR, 2009a) to resolve the looming issue. Instead of assigning the exact date of birth, they suggested that personal identification numbers would be generated using an adjacent available date in the same month as the birth date of the individual. Following a debate in the parliamentary chamber, the proposition to change the civil registration law was accepted on 25 March 2009 (SR, 2009b)[1].

This lack of addressing capacity was not a problem unique to Sweden; the neighbouring state of Denmark, which uses a similar personal identification number called *CPR-nummer*, had already encountered and resolved the same issue in 2007 (CPR, 2021). However, their solution did not require modifying the date of birth. Instead, the structure of the four digits that follow the date of birth was changed, creating more address capacity while preserving the accuracy of the date of the birth.

Minute modifications involving technical details of civil registration technologies such as those I present above might appear trivial, but due to the ubiquity of the personal identification number in both Denmark and Sweden, these small changes had much more significant consequences for not only the residents who carry such numbers, but also for the branches of public administration who rely on the accuracy of the numbers.

The crucial point is that these kinds of identification numbers, used by not only Sweden and Denmark but all Nordic countries[2], are not simply for tools for civil registration. They have become de facto identifiers in many everyday tasks. Picking up prescription medicine at the pharmacy or accessing the loyalty programme of a supermarket chain might involve typing in the personal identification number, or the final four digits of the number might be used as the code for a keycard to access a storage locker or to enter the gym. Signing up for a mobile phone contract often requires one to present such a number, and for those who do not have regular personal identification numbers often encounter new challenges when laws surrounding the numbers change (Garcia, 2022).

As such, for nearly everyone who holds a Swedish *personnummer,* the Danish *CPR-nummer,* or the Nordic equivalents, the idea of having a different date of birth in their number would be at the very least surprising and it is likely to be outrageous for many. So, how did Sweden end up here, and how did Denmark avoid it? The answers to those questions are surprisingly pertinent for STS scholarship as they reveal much about the performative potentials of identification methods.

On the everyday use of Nordic identification numbers

In the Nordic countries, an identification number is assigned to every citizen at birth. And to those born with one, this identification number is an unremarkable construct: a number that everyone has, and that everyone has always had. Over the last five years I have bothered many friends and colleagues who were born with the number by asking them whether they could remember the first time they wrote their number down, or the first time they got it wrong. Almost none of them could point to a specific moment, although many guessed that it must have been early in primary school. Of course, this says as much about my age and location as anything else: The vast majority of those I have spoken to were born in Sweden after 1960. Since the four digits were introduced in Sweden in the late 1960s, anyone born around or after that date is likely to remember the number as an unchanging entity. Just two of my older colleagues, born in the early 1950s, could remember a time before the four digits were added to their numbers.

In contrast, those who receive the number later in life—for example by moving to a Nordic country to study or work—often find it novel and sometimes even shocking due to its ubiquity, but partially also because the number really does make many things more convenient. Booking a doctor's appointment is easier, picking up medicine from the pharmacy is easier, opening a bank account easier, even renting a flat is easier, once the newly arrived resident is in possession of a personal identification number. Not only that, but the ubiquity of the number in everyday life is rarely remarked upon aside from moments of malfunction or rupture, as befits any infrastructure. Unsurprisingly, these friends and colleagues who moved to Sweden later in life could provide much more specific answers about when they had first written down their number ("as soon as I opened the letter from the tax office"), and the first time they had gotten it wrong ("the first time I tried to say it out loud").

There is of course a third category: Those who have never had such a number. For them, whom I have spoken to most often at conferences, the number tends to invoke the spectre of the surveillant state out of control—again, mostly an indication of the kinds of fields I work in rather than any sort of a representative sample—and there is much substance to their critique. The histories of numbering people in Europe are fraught with the worst excesses of violence committed by states against their own citizens. The literature on the topic is vast, and the surveillant capacities of new technologies for tracking and recording the daily lives of individuals for the purposes of social sorting, whether in service of the state or in the hands of multinational corporations, should give us all pause (Ball et al., 2012; Gilliom, 2001; Lyon, 2001; Monahan, 2013). However, my goal in this paper is not to argue for what the Nordic number should or should not do, but rather to demonstrate what it does in action.

In this paper, I analyse the Swedish and Danish personal identification numbers as methods for knowing and governing populations. To do so, I draw on two assertions from the study of methods within Science & Technology Studies: Methods are performative (Law, 2004), and they produce multiple objects and realities (Mol, 2002) Through my analysis, I demonstrate how such identification numbers enact individuals and populations simultaneously, and I identify a fundamental tension between them: one emphasising the representational potential of the part and another favouring the coherence of the whole. I conclude by arguing that issues surrounding these Nordic identification numbers can be traced back to a fundamental tension in addressing individuals that is impossible to resolve via technical modifications, although those interventions are crucial to keeping the systems operational.

Nordic identification numbers

While most countries across the world use some form of tax identification number for administrative purposes (OECD, 2021), and many other European states assign unique identifiers to the whole population beyond taxation purposes, the Nordic[3] identification numbers have several properties that allow us to understand them as a 'family' of numbers. The first similarity is their syntax. They all begin with the date of birth, sometimes include a separation symbol—usually a dash, occasionally a plus sign—and end with four or five digits, the assignment of which follows relatively similar rules across the five countries[4]. Equally significant is the similarity in their everyday usage in that they tend to appear in encounters with non-state institutions and companies just as much as they do in the context of civil registration. Finally, in all Nordic countries, the unique identification numbers assigned to citizens and residents remain with them for life.

These numbers are highly useful from the perspective of the state, as they allow for the generation of accurate statistics on the population, especially when combined with a system for the registration of births and deaths in a timely manner. Employment, welfare, migration, and education are all governed with the help of identification numbers in the Nordic countries. As such, these numbers have been of interest to statisticians and epidemiologists (Ludvigsson et al., 2009) due to the key role that they play in state-held registers which are highly valuable for research in both disciplines. Beyond these two groups, the last decade has seen a steadily growing interest in understanding the number from humanities and social sciences perspectives. Notable publications have covered the history of the number in Iceland (Watson, 2010), Denmark (Krogness, 2011), and Sweden (Paulsson, 2016), while two master theses have provided interaction design-centric histories of the number in Norway (Frestad, 2017), and Finland (Wessman, 2018).

In a study of the history Danish population registers and the CPR number, Bauer (2014) describes how the personal identification number moved from its role as administrative infrastructure to a biomedical resource used for population health research. Drawing on previous scholarship on studies of calculation, the history of statistics, and science studies perspectives, she argues that population data do not merely representations populations but act as infrastructures that produce populations. This key infrastructural role is also emphasised in Nordfalk and Hoeyer's (2020) analysis of a failed system for citizens to opt out of register-based research in Denmark.

In line with Verran and Lippert's (2018) observation that numbers often feature in STS scholarship, Tupasela et al. (2020) highlight the role of identification numbers across the Nordic countries in their analysis of the emergence of a "Nordic data imaginary" where health and welfare data collected by the state is shared with the private sector to boost economic growth. Alastalo and Helén (2021: 16) take the Finnish personal identification number *henkilötunnus* as their object of analysis when they argue that the number "epitomizes an intersection of political practices of governing people and advanced data management technology" and acts as a means for the state to both care for their citizens and to control them.

The performativity of identification methods

To claim something is "a method" is to say that it obeys a set of rules for organising knowledge, that it orders some things in a certain way while othering the rest. In studies of method in STS and related fields, previous work has established the notion that methods are performative. They do "not only describe but also help to produce the reality that they understand" (Law, 2004: 5), and they enact multiple objects and realities (Mol, 2002). These multiple objects and realities do come into conflict with one another; occasionally "one reality wins" (Mol, 2002: 53–86), and at other times they co-exist in tension with one another. They also come with their own experts, and the institutions that uphold the validity of the method.

There are two key moments in understanding how methods enact realities. As Lury and Wakeford describe:

> "Our proposal, then, is that the inventiveness of methods is to be found in the relation between two moments: the addressing of a method – an anecdote, a probe, a category – to a specific problem, and the capacity of what emerges in the use of that method to change the problem." (Lury and Wakeford, 2012: 7)

The moment when a method is applied to a problem, and how the problem changes because of that application are both crucial to understanding the consequences of methods. Focusing on these two moments does not imply that the problem itself exists independently of the methods; the moments themselves are simply analytical tools to help us bracket a process so that it can be understood. The inventiveness of methods, as a way of studying methods is itself an invention, as also expressed by the notion of "the double social life of methods" (Law et al., 2011).

Connecting these perspectives to identification and state practices is the notion of subjectivation; methods shape the subjectivities that we all inhabit, for example in how subjects are brought into being by methods used by the state such as the population census (Ruppert, 2011). Understanding methods as forces of subjectivation (Cakici and Ruppert, 2020), that is, socio-technical arrangements that configure the agency of subjects to act, allows us to seek how social and political subjectivities can arise from the technical features of identification methods. In relation to Nordic identification numbers, the date of birth and the following digits each codify assumptions about the size of the population, its rate of growth, as well as about age and gender, which I describe in greater detail in the following sections.

Methods contribute to the construction of the objects they set out to study, but this is not to say that methods of population statistics are the only devices for creating subjects; rather, as with many other devices, they have the potential to construct new subjects as they claim the population and the individual as their objects.

This process of construction is nowhere clearer than in the domain of expert practice as made visible in the reports, papers, and regulations (Hull, 2012; Mathur, 2016; Mitchell, 2002). Personal identification numbers construct a site of intervention for policies that target subjects as unique individuals. This site is then accessible by other knowledge practices, whether in the name of state policy, e.g. the population census, or individual taxation, or for private enterprise such as linking a mobile phone contract to a personal identification number. It serves a dual-purpose in that it allows the formation and addressing of groups based on the properties of the number ("everyone born on May 18th, 1998") or in the addressing of individuals separately ("the person assigned the number 19560101-0101").

It is not only external actors that intervene in the site of the personal identification number; self-conceptualisations also find their realisation in the very same site. The individual indicators of date of birth and legal sex at birth are both concerned with specific bodies, and both have become sites of contestation that are also targeted for intervention by the state.

In short, the composite form of the personal identification number as a date of birth followed by a set of identifying digits brings into being a unique method; one that gives rise to interventions that can target parts as individuals and wholes as the total population. It is in relation to these perspectives that I analyse Nordic identification numbers as methods that enact populations.

Identification and categorisation

Nordic identification numbers are but one example of a highly diverse group of identification methods. Earlier research on identification and registration has established the importance of these methods for knowing and governing populations (Anderson, 2015; Hacking, 1990; Ruppert, 2014), as well as its many risks when it comes to ever-expanding surveillance of subjects (Kertzer and Arel, 2001; M'charek, 2000; Nobles, 2000). These activities can be understood as attempts to make society and people legible to the state, and constitute central problems of statecraft (Scott, 1998).

Numbers have always played a prominent role in the exercise of state power in this manner. The history of statistics and its methods for handling uncertainty have been widely studied as social accomplishments (Daston, 1988; Desrosières, 1998; MacKenzie, 1981; Porter, 1996; Stigler, 1990). In this sense, numbers are the foundation on which contemporary states are built, whether in creating populations by counting them (Hacking, 1990), exercising power through experts (Mitchell, 1991), or shaping people and territory from a distance (Scott, 1998).

Since the origins the modern state dovetail with that of centralised identification systems, both seemingly mundane technologies such as identification cards (Caplan and Torpey, 2001) as well as biometric technologies and new infrastructural projects have been the focus of scholarly attention. Bennett and Lyon (2008) collect the diverse implementations of this identification technology in different geographies and through different technologies. Spektor (2020) describes a case where concerns about security seek to both mobilise and oppose new identification technologies, while Thiel (2020) highlights the role of interoperability in public debates and political decisions surrounding identification infrastructures, and Singh (2019) argues for seeing such technologies as translations that distribute accountability and control across bureaucracies.

Scholars have studied issues of categorisation and identification as performative methods. Grommé and Scheel show how statistical identity categories for migrants and minorities constitutes a site for the enactment of national identities, therefore bringing into being more than just the groups that they name (Grommé and Scheel, 2020). The changing objects and enacted realities also affect the method itself. For example, Dagiral and Singh (2020) show how digital identification infrastructures in France and India are changing the relationship between the state and the citizen by making each legible and accountable to one another in unforeseen ways. Moreover, Pelizza has argued that by viewing identification as performative, we can also see beyond the notion of identification as nothing more than a flawed representation; performativity foregrounds the process of translation and makes visible both the limitations and the materiality of the process (Pelizza, 2021). This focus on materiality also highlights the role of routine practices and social relations of humans which are often essential to the stabilisation and regular functioning of digital identification infrastructures (Chaudhuri, 2019).

Studying identification numbers

In my analysis of identification numbers, I draw on official reports and information published by state institutions in charge of the identification number systems in the Nordic countries. Typically, these are the tax offices and statistics agencies, but also include institutions that are specifically responsible for the administration of the number, for example *CPR-kontoret (the Danish central person registry office).* When describing instances of numbers running out and the change in civil registration law, I have also made use of Swedish parliamentary records from 2009, as well as news articles that reported on related issues in Sweden and Denmark between 2010 and 2022. Finally, I have used reports and guides published by *Skatteverket* (the Swedish Tax Agency) and *CPR-kontoret* when explaining the internal structure and the technical details of the personal identification number systems. I sorted the documents into three categories (parliamentary records, expert reports, and news), labelled according to country of origin, publishing institution, language, and publication date. Then, I developed a coding frame based on registration of life events which resulted in three themes relating to events (birth, death, migration), and four themes related to features of civil registration systems (population register, identification number, syntax, semantics). While this coding frame did not necessarily map the documents to a singular timeline, in the following sections I present the various parliamentary debates, reports and changes in law in chronological order for clarity.

As I described in the introduction, both Denmark and Sweden faced the problem of running out of personal identification numbers. In Sweden, the solution was to change civil registration laws to allow for numbers not matching the date of birth to be assigned to citizens and residents in 2009. In Denmark, the problem arose earlier due to the smaller representational capacity of the number, but their solution involved changing the internal structure of the number. Importantly, it is these very structures that encode assumptions about the world that the number inhabits, and changing one is to change the other as well. However, to understand the social and political implications of the internal structure of the number, we first need to understand how the personal identification number is constructed in the Nordic countries.

Making Up Numbers

Despite the name, the Nordic personal identification number is in fact a composite of several numbers that obey different rules. The first sequence is the date of birth where digits denote the day, the month, and the year. The second sequence of four or five digits are primarily used to distinguish between different people born on the same date, but throughout the history of the number they have been used as indicators for the region of birth, the legal gender, checksum (error detection), and even whether the bearer belongs to the royal family.

As an example, if a person born on 30 October 2022 were to be issued a *personnummer* in Sweden today in line with the Swedish guidelines (Skatteverket, 2021), the number might look like the following:

20221030-5013

If the same person were to be issued a *CPR-nummer* in Denmark, according to the Danish guidelines (CPR, 2021) they might receive the following number instead:

301022-4127

The numbers look similar aside from the difference in how the day, month, and year is represented. The former is in YYYYMMDD order using eight digits, while the latter is in DDMMYY order using only six digits. The date is followed by a dash to separate the suffix comprising four digits. By combining the date of birth with four additional digits, it would be possible to uniquely represent up to ten thousand individuals per day—or 3.6 million per year—in the absence of any other constraints, but in practice the four digits are used for other purposes as well, and the representational capacity is significantly smaller.

Regardless of the exact capacity, however, this kind of structure comes with an assumption of how about many people are likely to be born on any given day, and how that might change in the future. What the designers of the number must have had in mind for the kinds of numbers used in the Nordic countries were expectations of a certain population; closer to ten million rather than one billion. In other words, embedded in the design of the number itself is a population projection based on the assumption of sustained reproduction. Such political visions are often built into infrastructure, as Bowker and Star (2000) have also argued, and the Nordic identification number, in its capacity to act as an addressing infrastructure for the state, is no different.

The other feature shared across all Nordic identification numbers is the use of the date of birth based on the Gregorian calendar. Using the calendar for the registration of births is not unusual by any means; the right to birth registration is contained in the United Nations Convention on the Rights of the Child, Article 7 (UN General Assembly, 1989), and for most birth registration systems this means recording the birth event together with the date of the event. In Sweden, the calendar provides yet another link between dates and individuals through the tradition of a name day, itself a remainder of the calendars for the "saint of the day", that is, the association of specific dates with specific names of saints.

When numbers run out

It is currently possible to be assigned a personal identification number that differs from your actual date of birth in Sweden, because numbers for some dates have already run out. The reason for the limited capacity of personal identification numbers is in how they are generated from using the date of birth, but to understand how such numbers could possibly run out, we need to understand two other factors that contributed to the issue.

The first is migration to Sweden from other countries: Since the Swedish number can only address one thousand people per date of birth (in practice this number can be slightly lower due to reserved digits), and numbers are rarely released even if people move out of Sweden, it is possible to see how some days could come close to maximum capacity; extremely unlikely, but theoretically possible. Note that the number can represent approximately 36 million individuals per century (assuming a lifespan of a hundred years) and birthdays tend not to be uniformly distributed, i.e., some months tend to have more births than others; under these conditions more than one thousand people resident in Sweden could share the same date of birth for a given day. However, this is highly unlikely given the current population of Sweden[5]. In fact, a Statistics Sweden report published in 2016 estimated that approximately 300 numbers out of one thousand are claimed for each date under regular conditions (SCB, 2016).

The second factor that led to numbers running out was the decision to assign arbitrary dates of birth to people arriving in Sweden if they did not possess the kind of documentation recognised by the Swedish Migration Agency. If someone arriving in Sweden either did not hold an identification document that indicated the date of birth, or if the document itself was not recognised as a legitimate document by the Migration agency, then the individual in question was assigned either January 1st or July 1st as their day of birth, depending on which half of the year they declared their date of birth in. The required conversions from the Hijri calendar to the Gregorian calendar may have also played a role in this decision, as noted by one Skatteverket employee interviewed by Sverige Radio in 2019 (Boucheloukh and Axelsson, 2019). This decision gradually led to irregularities in population statistics, initially concentrated around certain years in the 1970s and 80s, as January and July 1st both seemed to indicate days where the number of births were higher than in the rest of the year (SCB, 2016: 18). However, a more serious problem soon arose: Since the personal identification number can only address a theoretical maximum of one thousand people per day, the artificial birth date assignments eventually exhausted the available supply of numbers for January 1st and July 1st of certain years. The issue was initially addressed by multiple state institutions in a series of reports and followed by a change in the civil registration law in 2009 (SR, 2009b) which allowed for personal identification numbers to be generated using an adjacent available date if the exact date of birth happens to be unavailable in the system.

As I discussed in the introduction, this lack of addressing capacity was not unique to Sweden. A similar problem was also recognised in Denmark in the early 2000s. A common feature of the Swedish and the Danish identification numbers is the use of an independent checksum digit within the number that allows for error control[6]. The trade-off is that such a feature also uses up a digit that could otherwise be used to increase the addressing capacity of the number. It is this feature that was removed from the Danish identification number on October 2007, resulting in an increase in the addressing capacity by a factor of ten (CPR, 2021).

In short, the Swedish and Danish authorities faced similar problems of identification numbers running out but settled on different technical solutions to increase the addressing capacity of the numbers. In the Swedish case, legislation allowed for people to be assigned personal identification numbers that do not match their date of birth, therefore allowing the dates that fill up to overflow into the next available date. In the Danish case, the removal of the checksum functionality increased the capacity of the number by a factor of ten, preserved the accuracy of the date of birth, and resolved or at least postponed the problem for several decades.

Discussion: The socio-politics of numbers

While the modifications to the Swedish and Danish identification systems I outlined in the previous section may appear minor, the scope of these technologies—national identification numbers that cover the whole population—spread their consequences far and wide.

In the Swedish case, it became possible to assign people personal identification numbers that do not match their date of birth, even when their actual date of birth is recognised by state authorities. Thus, the personal identification number is no longer a completely reliable indicator of the date of birth. Admittedly, this group is likely to make up a fraction of the population, but the undoing of deep-seated assumptions about the factuality of numbers still creates problems for other systems that rely on those numbers[7]. We can easily imagine an example where a form requires someone to submit both their personal identification number and the information on their passport. If the date of birth on those two do not match, a form-checker might easily throw up an error or outright refuse a form. Similarly, a border control agent unaware of the minutiae of Swedish personal identification numbers might suspect the individual of wrongdoing due to mismatches birthdates in the provided documentation. In fact, this was exactly the case that was reported by SR in 2019 that I cited earlier where a Syrian citizen with a Swedish residence permit was stopped and questioned at the Greek border while returning from vacation (Boucheloukh and Axelsson, 2019).

In the Danish case, the consequences become apparent in a longer chain of dependencies. Since the checksum digit was repurposed to make space for additional numbers, any systems that relied on the previously intended functionality of the checksum[8] erroneously started flagging some numbers as invalid after the change. The problem was sufficiently widespread that the CPR office was required to make a public statement declaring that "even though CPR office has been asking since 2007 for IT systems to be built to handle numbers that do not contain the modulo 11 digit", the office is still receiving questions and complaints from individuals whose numbers were rejected by IT systems (CPR, 2022). In the statement, the CPR office also stated that such systems should at minimum allow for CPR numbers without the modulo 11 digit to be entered manually.

In comparing the two cases, we see that the intervention of the Swedish authorities preserved the integrity of the system at the cost of the accuracy of individual representation. In other words, the coherence of the whole was prioritised over the specificity of the parts. Consequently, a group of individuals will need to personally account for the changes wherever they encounter friction, while the existing administrative systems can continue to function as before. The Danish case demonstrated exactly the opposite: the specificity of the parts was preserved at the cost of reducing the coherency of the whole. However, since the intervention removed the very mechanism built to check the validity of the number in local contexts, it left individuals who encounter issues with no clear understanding of the reasons for the problem, as the as the absence of the checksum nearly impossible to recognise in the number itself compared to seeing two different birth dates in two different documents. At the same time, as the checksum was always meant for national systems rather than international systems, the Danish state was able to intervene in the process as demonstrated by the statement published by the CPR office regarding the checksum digit. In that statement, the responsibility for handling the problem was placed at the level of IT system implementation at local authorities using CPR numbers, rather than on the person bearing the non-compliant number.

I have narrated these two moments of change in the national identification systems of Sweden and Denmark to argue that the use of the date and time for registration may appear mundane, but it is by no means free from social and political assumptions. As Bourdieu (2015: 20) has described, we only need to look at the ubiquity of the calendar as a shared organising practice to see the hegemonic power of the state over life. The calendar is one site where the state exercises an often-invisible power over social relations, and a state-issued number that includes the date of birth inherits the same form of power. It is easy to accept that the calendar—understood as the state-sanctioned method for compartmentalising time—is likely to remain stable, and that stability is one of the factors that makes Nordic identification number a reliable method for addressing individual state subjects.

This stability across time allows personal identification numbers to construct an equally stable site of intervention for policies that target subjects as unique individuals. It is this site that is then accessible by other knowledge practices, whether in the name of state policy, e.g., the population census, or individual taxation, or for private enterprise such as linking a mobile phone contract to a personal identification number. It serves a dual-purpose in that it allows the formation and addressing of groups based on the properties of the number ("everyone born on May 18th, 1998") or in the addressing of individuals separately ("the person assigned the number so and so"). Drawing on Deleuze (1992), Bauer argues that in this process the individual and the population are no longer conceived as opposites as the "'dividual body' is reassembled and enacted through statistical strata" (Bauer, 2014: 207). It is this melding of the individual and the population that defines the Nordic identification number; its immense utility to statisticians, epidemiologists, tax offices and many other state institutions arises from its power to enacts the individual and the population as sites of intervention.

The significance of addressing parts and wholes via numbers was already highlighted by Georg Simmel:

> "This contrast in ways of naming things reveals a complete antagonism in the sociological position of the individual within the spatial sphere. The individualistic person, with their qualitative determinacy and the unmistakability of their life contents, therefore resists incorporation into an order that is valid for everyone, in which they would have a calculable position according to a consistent principle. Conversely, where the organisation of the whole regulates the achievement of the individual according to an end not located within him or herself, then their position must be fixed according to an external system. It is not an inner or ideal norm but rather the relationship to the totality that secures this position, which is therefore most suitable determined by a numerical arrangement." (Simmel, [1908] 1997: 149–150)

Simmel's argument is that if individuals are not considered in terms of innate characteristics, then they can only be distinguished or judged on the basis of relations to a larger whole, and numbers are well-suited for this kind of work, although they are rarely meaningful as individual entities. To make sense of them, there is always a need to know about other numbers in relation to each other, for example to judge whether they indicate a quantity or form a sequence[9]. Forming the kinds of relations that then derive meaning from a totality depends on making things align with one another and become commensurable[10]. In the case of the Nordic identification number, combining the stability of the site of intervention based on the calendar and the relationship of individual sites to the whole, generates addressable subjects of the state[11].

Returning to the Simmel quote above, it is not only the enumeration of people and the crafting of a population alone that is of interest, but the possibility that numbers can be made to envelop a totality, or how a totality can be accomplished through these numbers: People are born, people die, the formatting of numbers changes, dates and calendars are swapped, but the idea of addressing a space through incrementing numbers, or describing that space through quantity persists throughout. It is this feature of the method that stabilises the population as a totality. The numbers belong to an orderly continuity, each day following from the next, and each day containing a finite number of people born on that day. That orderly continuity is the totality that persists past the birth and death of individuals. The interventions of the Swedish and Danish authorities to modify the national identification numbers challenge this continuity and foreground the tensions between the coherence of the whole and the representational potential of its parts, with consequences for all who carry such numbers.

Conclusion: The aftermath of performative power

In this paper, I have argued that the personal identification number enacts individuals and populations simultaneously. This is because of the composite form of the number—the date of birth followed by a set of identifying digits—brings into being a unique method that can address both individuals and the total population. However, these two sites of intervention, which I have theorised as parts and wholes, are at tension with one another. The former shapes a consecutive totality through the enumeration of calendar days while the latter provides features specific to the individual number. This is the fundamental tension that exists at the heart of the number; given the current structure and the syntax of the Nordic identification number, a richer representation of the individual through increased features in the number can only come at the expense of group coherence, and vice versa.

When other events bring the tension to the foreground, such as when the numbers ran out in Sweden and Denmark, technical modifications can bring solutions in the form of compromises by emphasising one site over the other. In the two cases I examined, the technical modifications served to keep the system functioning by finding a balance between group coherence and the features of individual numbers. The Swedish intervention preserved the former, while the Danish one did the opposite. However, as the tension is fundamental to the construction of the method, neither could resolve it.

What makes this tension significant beyond its representational capacity is that in the Nordic countries, the personal identification number sits at the heart of a centralised system of civil registration. Thus, any changes to the system, no matter how trivial, have the potential to affect all individuals in the population. As with a pebble dropped into still water, the technical modifications to the personal identification number produce ripples that travel far because the intervention is at the very centre of the web of relations.

In both Sweden and Denmark, the technical modification was successful in the sense that the numbers are no longer at risk of running out. However, as I described in the issues faced by a Swedish resident at an international border and numbers being refused at the citizen service centres due to outdated software, the full consequences of the changes are still unfolding after nearly 15 years. In both cases, it is the individual bearing the problematic personal identification number who suffers the negative consequences directly, and due to no fault of their own.

It is not that personal identification numbers used in the Nordic countries are inherently good, evil, democratic, or totalitarian. It is that they are potent tools of statecraft that sit at the core of civil registration, and therefore have the potential to affect the lives of all who carry them. That is why any changes to these numbers, no matter how minor or mundane they might appear, can disrupt the lives of many.

In STS scholarship, this kind of tension has been theorised in connection to how methods, objects, facts, practices, etc. enact realities. Those realities can and do exist in parallel, but also come into occasional conflict. In his discussion of Annemarie Mol's interpretation enactment (cf. Mol, 2002), John Law describes it as attending to "the continued practice of crafting" (Law, 2004: 56). With my analysis, it is this feature that I seek to highlight in relation to identification systems, broadly understood.

We can conceptualise all identification systems as attempts to contain that very same tension between individual representation and group coherence. By attending to their continued practice of method, whether through analysing new legislation, following the actors, or seeking to understand the technical changes to the systems, we cast light on what sites of intervention they bring into being. Those sites are where we locate the subjects and subjectivities of methods, and it is from that vantage point that we can begin to ask questions about the political projects that these methods make possible.

References

Alastalo M and Helén I (2021) A code for care and control: The PIN as an operator of interoperability in the Nordic welfare state. *History of the Human Sciences*.: 09526951211017731.

Anderson MJ (2015) *The American Census: A Social History*. 2nd ed. New Haven: Yale University Press.

Ball K, Lyon D and Haggerty KD (eds) (2012) *Routledge Handbook of Surveillance Studies*. Routledge International Handbooks. London: Routledge.

Bauer S (2014) From Administrative Infrastructure to Biomedical Resource: Danish Population Registries, the "Scandinavian Laboratory," and the "Epidemiologist's Dream". *Science in Context* 27(2): 187–213.

Bennett CJ and Lyon D (eds) (2008) *Playing the Identity Card: Surveillance, Security and Identification in Global Perspective*. London: Routledge.

Boucheloukh N and Axelsson S (2019) Allt fler får personnummer med 'fel' datum. *Sveriges Radio*, 6 September. Available at: https://sverigesradio.se/artikel/7293962 (accessed 27 December 2022).

Bourdieu P (2015) *On the State: Lectures at the College de France, 1989 - 1992*. Cambridge: Polity Press.

Bowker GC and Star SL (2000) *Sorting Things Out: Classification and Its Consequences*. Cambridge: MIT Press.

Bratton BH (2015) *The Stack: On Software and Sovereignty*. Cambridge: MIT Press.

Cakici B and Ruppert E (2020) Methods as forces of subjectivation: experiments in the remaking of official statistics. *Journal of Cultural Economy* 13(2): 221–235.

Caplan J and Torpey JC (2001) *Documenting Individual Identity: The Development of State Practices in the Modern World*. Princeton: Princeton University Press.

Chaudhuri B (2019) Paradoxes of Intermediation in Aadhaar: Human Making of a Digital Infrastructure. *South Asia: Journal of South Asian Studies* 42(3): 572–587.

CPR (2021) Opbygning af CPR-nummeret. Available at: http://cpr.dk/cpr-systemet/opbygning-af-cpr-nummeret (accessed 23 April 2021).

CPR (2022) Personnumre uden kontrolciffer (modulus 11 kontrol). Available at: https://cpr.dk/cpr-systemet/personnumre-uden-kontrolciffer-modulus-11-kontrol (accessed 24 February 2023).

Dagiral É and Singh KM (2020) Governance and Accountable Citizenship Through Identification Infrastructures: Database Politics of Copernicus (France) and National Register of Citizens (India). *Science, Technology and Society* 25(3): 368–385.

Daston L (1988) *Classical Probability in the Enlightenment*. Princeton, NJ: Princeton University Press.

Deleuze G (1992) Postscript on the Societies of Control. *October* 59: 3–7.

Desrosières A (1998) *The Politics of Large Numbers: A History of Statistical Reasoning* (ed. RD Whitley; tran. C Naish). Cambridge, Mass.: Harvard University Press.

Frestad HN (2017) *The Norwegian National Identification Numbering System: The History of a Design Process*. Master's Thesis. NTNU.

Garcia R (2022) Här nekas Silvana mobiltelefoni – nya lagen skapar problem. *SVT Nyheter*, 21 December. Available at: https://www.svt.se/nyheter/lokalt/smaland/ny-lag-asylsokande-kan-sta-utan-mobilabonnemang (accessed 22 December 2022).

Gilliom J (2001) *Overseers of the Poor: Surveillance, Resistance, and the Limits of Privacy*. Chicago: University Of Chicago Press.

Grommé F and Scheel S (2020) Doing statistics, enacting the nation: The performative powers of categories. *Nations and Nationalism* 26(3): 576–593.

Hacking I (1990) *The Taming of Chance*. Cambridge: Cambridge University Press.

Hull MS (2012) *Government of Paper: The Materiality of Bureaucracy in Urban Pakistan*. Berkeley: University of California Press.

Kertzer DI and Arel D (2001) *Census and Identity: The Politics of Race, Ethnicity, and Language in National Censuses*. New Perspectives on Anthropological and Social Demography. Cambridge: Cambridge University Press.

Krogness KJ (2011) Numbered Individuals, Digital Traditions, and Individual Rights: Civil Status Registration in Denmark 1645 to 2010. *Ritsumeikan Law Review* 28: 87–126.

Law J (2004) *After Method: Mess in Social Science Research*. London and New York: Routledge.

Law J, Ruppert E and Savage M (2011) The Double Social Life of Methods. CRESC Working Paper Series, Paper No. 95.

Ludvigsson JF, Otterblad-Olausson P, Pettersson BU, et al. (2009) The Swedish Personal Identity Number: Possibilities and Pitfalls in Healthcare and Medical Research. *European Journal of Epidemiology* 24(11): 659–667.

Lury C and Wakeford N (eds) (2012) *Inventive Methods: The Happening of the Social*. London: Routledge.

Lyon D (2001) *Surveillance Society: Monitoring Everyday Life*. Buckingham: Open University Press.

MacKenzie DA (1981) *Statistics in Britain, 1865-1930: The Social Construction of Scientific Knowledge*. Edinburgh: Edinburgh University Press.

Mathur N (2016) *Paper Tiger: Law, Bureaucracy and the Developmental State in Himalayan India*. Cambridge: Cambridge University Press.

M'charek A (2000) Technologies of Population: Forensic DNA Testing Practices and the Making of Differences and Similarities. *Configurations* 8(1): 121–158.

Mitchell T (1991) The limits of the state: Beyond statist approaches and their critics. *American Political Science Review* 85(1): 77–96.

Mitchell T (2002) *Rule of Experts: Egypt, Techno-Politics, Modernity*. Berkeley: University of California Press.

Mol A (2002) *The Body Multiple: Ontology in Medical Practice*. Durham: Duke University Press.

Monahan T (ed.) (2013) *Surveillance and Security: Technological Politics and Power in Everyday Life*. New York: Routledge.

Nobles M (2000) *Shades of Citizenship: Race and the Census in Modern Politics*. Stanford: Stanford University Press.

Nordfalk F and Hoeyer K (2020) The rise and fall of an opt-out system. *Scandinavian Journal of Public Health* 48(4): 400–404.

OECD (2021) Tax identification numbers (TINs) - Organisation for Economic Co-operation and Development. Available at: http://www.oecd.org/tax/automatic-exchange/crs-implementation-and-assistance/tax-identification-numbers/ (accessed 2 March 2021).

Paulsson A (2016) The Welfare State That Wanted to Keep Track of Its Citizens: Personal Identity Numbers as Administrative Technology. *Modernizing the Public Sector: Scandinavian Perspectives*: 80–95.

Pelizza A (2021) Identification as translation: The art of choosing the right spokespersons at the securitized border. *Social Studies of Science* 51(4):487–511.

Porter TM (1996) *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton: Princeton University Press.

Riksdagsförvaltningen (2019) Avvikande personnummer Interpellation 2018/19:296 Angelica Lundberg (SD) - Riksdagen. Available at: https://www.riksdagen.se/sv/dokument-lagar/dokument/interpellation/avvikande-personnummer_H610296 (accessed 28 February 2023).

Ruppert E (2011) Population Objects: Interpassive Subjects. *Sociology* 45(2): 218–233.

Ruppert E (2014) Infrastructures of Census Taking. In: Darroch G (ed) *The Dawn of Canada's Century: Hidden Histories*. Montreal: McGill-Queen's University Press, pp. 51–78.

SCB (2016) *Personnummer*. Bakgrundsfakta – Befolknings- och välfärdsstatistik 2016:1. Statistiska Centralbyrån.

Schinkel W (2016) Making Climates Comparable: Comparison in Paleoclimatology. *Social Studies of Science* 46(3): 374–395.

Scott JC (1998) *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven: Yale University Press.

Selmer ES (1964) Personnummerering I Norge: Litt Anvendt Tallteori Og Psykologi. *Nordisk Matematisk Tidskrift* 12(1/2): 36–44.

Simmel G (1997) *Simmel on Culture: Selected Writings* (eds D Frisby and M Featherstone). London: SAGE.

Singh R (2019) Give Me a Database and I Will Raise the Nation-State. *South Asia: Journal of South Asian Studies* 42(3): 501–518.

Skatteverket (2021) Personal identity numbers and coordination numbers. Available at: https://www.skatteverket.se/servicelankar/otherlanguages/inenglish/individualsandemployees/livinginsweden/personalidentitynumberandcoordinationnumber.4.2cf1b5cd163796a5c8b4295.html (accessed 23 April 2021).

Spektor M (2020) Imagining the Biometric Future: Debates Over National Biometric Identification in Israel. *Science as Culture* 29(1): 100–126.

SR (2009a) Personnummer och samordningsnummer Proposition 2008/09:111 - Riksdagen. Available at: https://www.riksdagen.se/sv/dokument-lagar/dokument/proposition/personnummer-och-samordningsnummer_GW03111 (accessed 6 December 2022).

SR (2009b) Personnummer och samordningsnummer Skatteutskottets Betänkande 2008/09:SkU28 - Riksdagen. Available at: https://www.riksdagen.se/sv/dokument-lagar/arende/betankande/personnummer-och-samordningsnummer_GW01SkU28 (accessed 6 December 2022).

Stigler SM (1990) *The History of Statistics: The Measurement of Uncertainty before 1900*. Cambridge: Belknap Press.

Thiel A (2020) Biometric identification technologies and the Ghanaian 'data revolution'. *The Journal of Modern African Studies* 58(1): 115–136.

Tupasela A, Snell K and Tarkkala H (2020) The Nordic data imaginary. *Big Data & Society* 7(1): 2053951720907107.

UN General Assembly (1989) *Convention on the Rights of the Child*. 1577. United Nations. Available at: https://www.ohchr.org/en/instruments-mechanisms/instruments/convention-rights-child (accessed 27 December 2022).

Verran H (2001) *Science and an African Logic*. Chicago: University of Chicago Press.

Verran H and Lippert I (2018) After Numbers? Innovations in Science and Technology Studies' Analytics of Numbers and Numbering. *Science & Technology Studies* 31(4): 2–12.

Watson I (2010) A Short History of National Identification Numbering in Iceland. *Bifröst Journal of Social Science* 4.

Wessman E (2018) *Developments in personal identification - The Finnish henkilötunnus*. Master's Thesis. NTNU.

Notes

1 At the time of writing, it is still possible for personal identification numbers in Sweden to be assigned to an adjacent available date.

2 The Nordic countries are Sweden, Denmark, Norway, Iceland, and Finland.

3 Two Baltic states, Latvia and Estonia also assign identification numbers with similar properties, although the structure of the number differs slightly for the former and significantly for the latter.

4 One reason why these numbers resemble one another in syntax is because the experts and institutions that developed them were aware of each other's work. For example, in relation to the design of the Norwegian systems in 1960s, the experts voiced a desire to improve on the already existing system in Sweden (also see Frestad, 2017 for a history of the design process; Selmer, 1964).

5 Prior to 1990, the Swedish personal identification number also included digits that indicated the county of assignment which decreased its capacity significantly, and occasionally required regions to 'borrow' capacity from one another.

6 One function of the checksum digit is the prevention of transcription errors. Since the number was designed to be copied from place to place by hand, writing down digits one by one, its inclusion in the original design is aimed at preserving the integrity of the number. In the past the checksum would have also provided a small measure of security against fabricated numbers if the forger were not knowledgeable in the internal structure of the number, although in more recent times this checksum has been trivially easy to replicate given that all the documentation is publicly available over the Internet.

7 It is also worth noting that in 2019 the issue of numbers running out was brought up by Angelica Lundberg, a representative of the nationalist right-wing party Sweden Democrats, during a debate with the finance minister at the time, Magdalena Andersson of the Social Democrats (Riksdagsförvaltningen, 2019). Lundberg's argument was self-contradictory in that it asked for significant resources to be put in the service of resolving an issue that affects those who have migrated to Sweden, while at the same time positioning her party as being against the use of resources in this manner. However, regardless of the content of the argument, the consequences of the technical change in the personal identification number had political significance even at the parliamentary level.

8 The checksum digit is generated using a modulo 11 operation where each digit of the number is multiplied by another number called the weight. These are then summed together and divided by 11. Finally, the remainder is subtracted from 11 to obtain the checksum digit (CPR, 2021).

9 Verran's study of numbering practices describes how enumeration itself can also involve an oscillation between unity and plurality (Verran, 2001: 92–119).

10 Schinkel (2016) has argued that such alignment must begin by providing a basis for differentiation, and that this activity can be understood as "comparity work" (Schinkel, 2016: 377).

11 The notion of addressability has been employed by Bratton (2015) to analyse the power of information and communication technologies globally. Bratton (2015, 191–218) argues that the ability to assign addresses is "critical to any geopolitical system".

Rouse Joseph (2023) Social Practices as Biological Niche Construction. Chicago and London: University of Chicago Press. 352 pages. ISBN 9780226827957.

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Joseph Rouse is concerned with (re)conceptualizing practice and practices-in-practice as the basic element of human social life and human nature. In promoting a thorough-going contemporary philosophical naturalism, he argues that practice, episodes of humans doing their varied socialities in various situations as doings of their very being as lively social organisms, effect epistemic and moral norms simultaneously. The projects of describing the world and making judgements as agents, which Kant, inspired by Hume, separated out as distinct, are re-imagined as one.

Central to Rouse's most recent book is the issue of how challenges to cognitivism, arguing for explicit recognition of complex assemblages of institutional practice, might proceed. Rouse implicitly offers a radically novel working imaginary of human social life and human nature as based in institutional procedure and humans' practices-centred work. He cogently argues that humans' practices-centred work is an evolutional extension of the practices-centred work that non-human animals enact in living as particular non-human animals. The title names this using the appropriate technical concept: 'biological niche construction'. The book's chapter 2 is given over to making this argument.

The dominant ideology of cognitivism locates meaning, understanding, and critical assessment in individual minds and thought. Cognitivists see those human capacities as informed by bodily perceptions but assume analyses of social life that inform individual human social agency is mind-work. By contrast, a fully-fledged practice-based account emphasizes individual practices of embodied experiencing in situ, and subsequent articulation in wordings by individual participants, along with proceduralizations as practice in institutional functioning.

As a practitioner of sciences and technologies studies, I have been inspired by Rouse's writings for many years now, albeit my focus on using practices-based methods will seem remote from Rouse's theorising. My work has been driven by the need to manage on-the-ground relations between incommensurability and commensurability in working in epistemic good faith between disparate knowledge traditions. As a philosopher of science, Rouse is focused on theorizing contemporary human nature and human social life as an expression of a thorough-going philosophical naturalism that refuses the traditional Humean empiricist dichotomy of description and judgment (cf. Määttänen, 2022). Understanding Rouse's project this way positions it as both a direct descendant and potent challenger of the tradition of empiricism attributable to David Hume (cf. Prinz, 2015). Although Rouse mentions Hume only once in a minor footnote, and he does not propose this book as participating in a paradigm change, my claim is that it is not inappropriate to read it this way.

In the opening chapter of this latest contribution to his long-term project, Rouse suggests that at least three major challenges have in the past been mounted in opposition to the significant shift in conceptualizing human nature and the socialities that focus on practice spawns. He attends to these challenges in turn. First, he considers how best to analytically consider the interrelations between those who participate in practices and the contexts – the sociomaterialities – of their participation. Second, Rouse elaborates that "a central issue for practice-based conceptions [is] how performances [enactments] belong to and are enabled by or conditioned by a practice, and how that belonging together is sustained in and through subsequent performances" (p. 32). The third form of challenge is, in Rouse's opinion, central, if practice-based conceptions are to successfully challenge the dominant cognitivism in initiating and sustaining a major paradigm shift in philosophy and social sciences where "practices constitute a publicly accessible locus of meaning and understanding" (p. 32). In considering this third aspect, Rouse notes that there are alternative interpretations of where such public meaning-making and understanding is located:

> "One strategy emphasizes flexible bodily skills for coping with situations, including participants' embodied responses to one another's performances. Alternative strategies take different approaches to language use as a public domain that enables making sense of and responding to one another's performances in partially shared circumstances" (p. 32).

The substantive element of chapter one is an adumbration of the established means that theorists of practice-based approaches have developed in meeting these challenges. Having thus carefully listed and responded to challenges of the practice-based approach vis-à-vis the cognitivist, Rouse turns attention to those aspects in which it remains inadequate. He contends that these inadequacies lie in the social-theoretic form of conceptualising practice and of reading practices-in-practice. It is this formulation that is the target of Rouse's critique.

The book sets out to elaborate how the inclusion of the biological in conceiving 'a practice' makes good on the deficiencies of the social-theoretic accounting both the concept of 'a practice' and the articulating of 'practices-in-practice'. Practices-in-practice are actual enactments or performances of a practice generating meaning and understanding as a concept, which necessarily renders a particular account of the here-and-now, and simultaneously affords possibilities for judgements. Rouse proposes that the root difficulty with developing adequate conceptions of practice – as the basis of human nature and the forms of human sociality which that account of human nature precipitates – arises because the accounts offered are situated in an abstracted symbolic social realm. Practices have been ontologically separated out from the actualities of their biological significance in human ways of life.

As Rouse sees it, the challenge in conceptualizing a practice and appropriately reading practices-in-practice has two aspects. First, the social theoretic conceptualization of practice lacks a non-arbitrary basis for identifying temporally-extended and spatially-dispersed collective enactments as a practice-in-practice of this practice, and eventually this conceptualization of the world. Second, for that identification to be adequate, it needs to disclose the sources and expressions of the normative authority with which a practice both enables and influences emergent particular enactments, which might then be judged as good enough repetitions (p. 54).

With regard to the first aspect, he points out that practitioners need to be able to reliably specify why this enactment here-and-now counts (or does not) as practice bringing a particular concept to life – say a number. As a practice which has meaning as a particular concept, why does this enactment count as the concept of number, but not that enactment? In my experience, the difficulties Rouse is summarising here are real experienceable difficulties for the researcher who would use a practices-based method in inquiry. Rouse does not offer illustration of how these might be experienced, but for those for whom illustration helps grasp the problem, a vivid account of a researcher facing exactly this problem can be found in chapter one of my book Science and an African Logic (Verran, 2001). Accounted there too is experience of the second problem Rouse identifies with social-theoretic accounts of practice: the need to disclose the sources, and account expressions of, normative authority. I elaborate the confusion and discomfort of experiencing exactly those tensions Rouse names as an aporia.

Rouse provides an account of the origins of institutional practice as biological, which affords the claim that human nature and the material socialities that emerge in its workings are 'practices all the way down'. In doing so, it plugs a significant hole in the project of articulating a naturalist form of sociality. As I read the significance of the book, this is where Hume as antecedent comes in. Kant did a job on Hume's 'story' concerning experience and human nature, rendering senses as enabling description and knowledge claims which afforded judgements as social norms, which in turn afforded the possibility of articulating practices generating social goods. Rouse's account of practices however turns Hume's story inside out. After Rouse it can be seen how these steps might flow in the opposite direction. Practices of human 'doings', with their varied socialities and various situatedness, effect epistemic and moral norms. Participation (more or less competent) in those practices that effect epistemic and moral norms is what is experienced. The task of the researcher is to account participation, reflexively account the competence, and tease out the epistemic and the moral, in discerning, for example, those practices that inflict epistemic or moral harm, and how they do so.

References

Määttänen P (2022) Facts and Values After David Hume. *International Journal of Semiotic Law* 36: 17–29.

Prinz J (2015) Hume and Cognitive Science. In: Russell P (ed) *The Oxford Handbook of Hume*. Oxford: Oxford University Press, pp. 777–792.

Verran H (2001) *Science and an African Logic*. Chicago and London: University of Chicago Press.

Schmidt Jan Cornelius (2022) Philosophy of Interdisciplinarity: Studies in Science, Society and Sustainability. London and New York: Routledge. 216 pages. ISBN 978-1032118468.

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Based on the diagnosis that "interdisciplinarity has lost its critical momentum" and has been reduced "to a trendy, tame, and toothless notion" (p. 1), the aim of Schmidt's *Philosophy of Interdisciplinarity: Studies in Science, Society and Sustainability* is not solely to clarify and classify the hyped terms or provide organization or management strategies. Instead, Schmidt intends "to strengthen critical voices amid the recent hype", and to argue for "a critical-reflexive program of interdisciplinarity conducive to a sustainable future for our knowledge society" (p. 2). Schmidt refers to the original spirit of interdisciplinarity as an environmentalist concept and supports visions of an essential change in human-nature relations, interested in a sustainable future of our late-modern knowledge society. This understanding of inter- and transdisciplinarity was originally advocated by Erich Jantsch at an OECD conference in the early 1970s, where Jantsch envisioned a 'self-renewal of the academy' (Jantsch, 1970; Jantsch, 1972). To similarly substantiate a program for a 'critical-reflexive interdisciplinarity', Schmidt makes use of the rich tradition of philosophy for case study analysis and develops a framework to disentangle the various forms of inter- and transdisciplinarity, making his approach a unique contribution to the discourse, being philosophic and interdisciplinary itself. As such, Schmidt's book can be inspiring for STS as well as for sustainability science, social ecology, environmental ethics, technology assessment, complex systems, philosophy of nature, and philosophy of science – all fields with which the book is explicitly concerned.

The book provides a thought-provoking differentiation, explication, and critique. Schmidt exposes different understandings of the terms of interdisciplinarity and transdiciplinarity and lays the groundwork for a critique of their myriad uses. The plurality of motives behind these notions and criteria characterizing their semantic core are presented concerning the existence of disciplinary or academic boundaries and the transgression or overcoming of those boundaries. Through a dialectic consideration of boundaries, with reference to well-established distinctions in the philosophy of science, Schmidt identifies four types of interdisciplinarity that have not been clarified clearly by other authors – interdisciplinarity regarding objects (1), knowledge, theories or concepts (2), methods or practices (3), and problems (4). He illustrates all four types via research programs that are labeled interdisciplinary, e.g. nano research and sustainability research, as well as many more. The complex relationship between interdisciplinarity and transdisciplinarity is particularly emphasized. On this basis, Schmidt develops his critical-reflexive concept of problem-oriented interdisciplinarity that seeks to go beyond what is typically associated with transdisciplinarity. This unique and clear terminological clarification forms the very basis for the book. In the following, I highlight and review four dimensions of the book's critical-reflexive perspective.

The first dimension of the book concerns a critique of the knowledge politics of interdisciplinarity. This dimension starts with the consideration that inter- and transdisciplinarity are not solely academic terms but also buzzwords in knowledge politics (p. 41). Schmidt uses his typology and provides a foundation for a critique of research programs that claim to be interdisciplinary. For instance, Schmidt analyses the US National Science Foundation's program for converging technologies, which advocates object-centred interdisciplinarity – the weakest type of interdisciplinarity. He argues that such a reflection on interdisciplinarity constitutes the very basis for a normative review and potential revision of recent research programs. A second dimension of the book then encompasses a critical take on object-oriented interdisciplinarity from a historical angle and relates it to the discourse on technoscience – a central notion for STS scholars (p. 55). Many recent technosciences are based (only) on object-oriented interdisciplinarity, which can be found already in the very core of the modern program of sciences. Schmidt's reflection upon the contemporary relevance of Bacon's ideal from the 16th century serves as a basis for a critique of object-oriented interdisciplinarity and its instrumentalist account. He argues that the Baconian program for the modern age is one-sided and here problematic, and links the historical analysis to the present-day discussion surrounding the label of technoscience. Technoscience and object-oriented interdisciplinarity prove to be twins that are not guided by societal problems, nor are they problem-centered.

A third dimension of Schmidt's book reflects upon the notion of 'problem'. Since the seminal work of Gibbons et al. (1994), the practices of *The New Production of Knowledge* are regarded as 'problem focused' and 'problem solving'. The discourse of inter- and transdisciplinarity is in particular a discourse on problems, which Schmidt explicitly focuses on. But what does a problem mean (p. 75)? According to Schmidt, a more critical-reflexive answer is possible and needed. He starts by elaborating what problem-oriented interdisciplinarity is not: object-, theory-, or method-oriented. The essential difference concerns the reflection on and revision of problems and, related to this, the focus on ends, goals, and purposes of interdisciplinary knowledge production. What follows is an in-depth explication of the notion of a problem as it relates to three knowledge elements: systems, targets, and transformative knowledge. Schmidt shows that this matches perfectly with the classic characteristics of action theories and a means/ends rationality. He critiques the instrumentalist orientation but also shows that some present-day practices and concepts of problem-oriented interdisciplinarity inherently carry a critical-reflexive momentum. This critique serves as an entry for his further argumentation in favor of critical-reflexive problem-oriented interdisciplinarity. To substantiate his approach, Schmidt refers to the critical-materialist, pragmatist, and phenomenological tradition, in particular to Jürgen Habermas' pragmatist discourse theory and the concept of communicative action.

Finally, a fourth dimension of the book is concerned with society-nature relations – and a critique of the dominant view of nature and humans (p. 102). Schmidt shows that (the discourse on) inter- and transdisciplinarity originally emerged in environmentalism. As part of this, Schmidt aims to push the problem-oriented type of interdisciplinarity beyond instrumentalist shortcomings. He argues that a novel understanding of nature is necessary to change the society–nature relations and human action in nature. Equipped with Hans Jonas' non-reductionist and non-disciplinary view of nature, this dimension advocates a critical-reflexive account. Sustainability problems reveal a fundamental cultural crisis in the human–nature relationship, mirroring a crisis of the academy and the university. Schmidt shows that a critical-reflexive type of problem-oriented interdisciplinarity can address this crisis. These theses share much with Latour's (2004) view that also aims at overcoming various dichotomies and argues for a new mindset.

Although the fourth dimension is based on a critique, namely the deficits of modern society-nature relations, Schmidt's book shows a direction in which we can proceed: a novel way of viewing nature based on alternative concepts of science and scientific knowledge (p. 123), and knowledge politics and technoscience assessment (p. 157f.). Schmidt argues that the sciences not only play an ambivalent role in the advancement of modern technology but are also intertwined with the environmental crisis: the way the sciences conceptualize nature is culturally constitutive of the human-nature relationship. Schmidt thus seeks alternative concepts and presents a case study of scientific developments beyond the mainstream since the 1960s: the interdisciplinary field of self-organization theory, nonlinear dynamics, and complex systems theory. These approaches advance a critique of the established classic-modern sciences and question central presuppositions relevant to methodology. The new interdisciplinarity approaches offer groundbreaking prospects, as for example instability is seen in a positive light. It is the source of complexity, pattern formation, and self-organization, which leads to a synthetic, process-ontological view of nature that resonates with the human experience of being a participant in nature.

Another direction of the above-mentioned fourth dimension of the book concerns a critical-reflexive approach in Technology Assessment (TA). TA is a perfect case for problem-oriented interdisciplinarity at the science–society interface. Schmidt discusses a specific approach in TA, namely Prospective Technology Assessment (ProTA), which includes critical-reflexive elements in a prospective assessment of science and technology in very early phases of new and emerging knowledge fields. He argues that the critical-reflexive concept of interdisciplinarity incorporated in ProTA can be regarded as 'meta-instrumentalist'. In sum, ProTA contributes to the self-critique and self-reflexivity of the science/technology system.

Concludingly, Schmidt develops in his well-structured book a new, unique, and critical approach to interdisciplinarity that goes far beyond other recent contributions (cf. Klein, 2021; Repko and Szostak, 2021). Schmidt argues that ''inter- and transdisciplinarity signify a thorn digging in the heart of the academy and the sciences'', and intends to ''facilitate a new critical-reflexive practice in and of the academy'' (p. 12). Therefore, the book can be seen as an extremely valuable read (not only) for STS scholars, as it follows a program of 'engaged STS' (Sismondo, 2008: 13), including the goal of bringing the sciences into democracy (Sismondo, 2008: 25; Latour, 2004). Critical-reflexive interdisciplinarity for a sustainable future of our late-modern societies frames nature and politics not as two separate domains, as Latour (2004) often stresses. Additionally, the book gives substance to – and clarifies – two central notions of STS: interdisciplinarity and transdisciplinarity[1]. As such, it contributes to foundational issues of STS. What is missing is a final chapter that would bring the different aspects together again, but the introduction and chapter summaries serve this purpose sufficiently.

References

Gibbons M, Limoges L, Nowotny L, Schwatzman S, Scott P and Trow M (1994) *The New Production of Knowledge*. London: Sage.

Jantsch E (1970) Inter- and Transdisciplinary University: A Systems Approach to Education and Innovation. *Policy Sciences* (1): 403–428

Jantsch E (1972) Towards Interdisciplinarity and Transdisciplinarity in Education and Innovation. In: CERI (ed) *Interdisciplinarity*. Paris: OECD, pp. 97–121.

Klein JT (2021) *Beyond Interdisciplinarity: Boundary Work, Communication, and Collaboration.* Oxford: Oxford University Press.

Latour B (2004) *Politics of Nature: How to Bring the Sciences into Democracy*. Cambridge: Harvard University Press.

Repko AF and Szostak R (2021) *Interdisciplinary Research. Process and Theory*. Los Angeles: Sage.

Sismondo S (2008) Science and Technology Studies and an Engaged Program. In: Hackett EJ et al. (eds) *The Handbook of Science and Technology Studies.* Cambridge: MIT Press, pp. 13–31.

Notes

1 For instance, the diagnosis of shift of knowledge production, such as 'mode-2', is strongly based on the notion of transdisciplinarity (Gibbons et al., 1994).

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