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To Catch a Cicada: A Case of Expert Listeners in a 'Little Science' Community

Thomas Alexander Corbin

Centre for Research in Assessment and Digital Learning (CRADLE), Deakin University, Australia / t.corbin@deakin.edu.au

Samantha Corbin

Walter and Eliza Hall Institute (WEHI), Australia

David Emery

Sydney School of Veterinary Science, University of Sydney, Australia

Nathan Emery

Independent Researcher, Australia

Christie Foster

Ramaciotti Centre, University of New South Wales, Australia

Alexander James Gillett

Macquarie University, Australia

Abstract

This paper examines the role of tacit knowledge and embodied sonic skills involved in catching cicadas (*Cicadoidea* Latreille in the order Hemiptera) for scientific study in Australia. Cicada researchers rely on identifying the unique "call patterns" of male cicadas to locate populations and track individuals to net. Drawing on an ethnographic study of the authors' own practices as cicada researchers, we demonstrate that cicada-catching involves tacit and embodied skills that are mastered in a community of practice that has a local epistemology centred on sonic skills for the multimodal production of knowledge. Through analysing their own cicada-hunting fieldwork, the authors demonstrate how sonic skills, as a form of active embodied knowing, enable the production of scientific knowledge.

Keywords: Cicadas, Sonic Skills, Tacit knowledge, Scientific communities, Citizen Science, Entomology

Introduction

Cicadas are a hallmark of the Australian summer soundscape. During the warmer months, it is common to see media outlets discussing the remarkable volume of sound generated by cicadas, often with headline-grabbing comparisons made to aircraft noise, rock concerts, or combustion engines.[1] But despite both their summertime ubiquity and vocality, relatively little is known in precise scientific detail about the cicada species which populate Australia. Perhaps the best example of this relative paucity of knowledge is the fact that even the exact number of species in Australia is unknown. Experts estimate that there are as many as 500-800 species (Corbin and Corbin, 2022; Emery, 2020), perhaps far more, which remain scientifically undescribed. This acts as a 'taxonomic impediment' (Taylor, 1983) to conservation in that unknown species cannot be protected (Sands, 2018; Foley, 2023). Partly this lack of knowledge is due to a lack of funding – cicadas do not pollinate, nor do they typically suit the needs of biotech research – but it is also due to the simple fact that cicadas are typically very difficult to catch. Not only are individual specimens wary and elusive; but they emerge in their adult stage either in such small numbers that are hard to detect at all, or otherwise, they emerge *en masse* in such large numbers that it makes identifying particular individuals within the surrounding cacophony remarkably challenging. Furthermore, many cicada species emerge only in highly localised remote regions and do so only opportunistically (and therefore unpredictably) during certain favourable conditions and survive for merely 1-3 weeks above ground.

The authors of this paper are members of a small amateur cicada research community – what we will refer to as the 'cicada hunting community' for reasons outlined later in the article – in Victoria and New South Wales, Australia. In what follows, we describe our own practices in the field. Our main goal is to explain in detail how cicada-catching involves tacit and embodied skills that are mastered in a community of practice that has a local epistemology that centres around sonic skills for the multimodal production of knowledge. Such an account of these scientific practices is currently missing from the literature as scientific papers documenting the identification of new cicada species focus on taxonomic details and song descriptions but do not outline the methods by which they are tracked and captured (e.g., Moulds, 1988; 2012; cf. Lorimer, 2008 on the challenges of documenting field skills). Popular works for lay audiences are available (e.g., Emery, 2020), but focus on species identification and general education on the superfamily. A more thorough account of the actual practice of catching a cicada is warranted for several reasons.

Firstly, there is an interest in Science and Technology Studies (STS) and philosophy of science around the tacit dimensions of knowledge (Polanyi, 1966) and local epistemologies (Longino, 2002). These are the ways in which scientific knowledge is produced in particular communities of practice and situated in particular material conditions. Since the 'practice turn' in science studies (Soler et al., 2014), and the move away from idealised conceptions of science towards what Latour (1987) called "science in action", theorists are increasingly interested in the scientific practices – tacit, material, and psycho-social – and what scientists actually *do*. Longino (1990, 2002) has argued, 'knowledge-productive practices' – involving material and intellectual elements – take place within a context of inquiry and how scientific findings are produced in contexts by social communities working together. Chang (2022: 18) has recently stressed that we should not think of scientific knowledge as primarily propositional, instead "active knowledge is at the core of scientific knowledge": it is in knowing for example, how to build a model, conduct an assay, make an observation by manipulating an instrument, or engage with a theory. Reasoning and observation are social processes, and so cognitive ethnographies of these practices can help deepen our understanding of science itself (Alač and Hutchins, 2004; Latour, 1987; Nersessian, 2005; Nersessian and MacLeod, 2022; Solberg, 2021). Currently, these details are overlooked in the etymological literature on cicadas which focuses on taxonomical details. Our paper addresses these omissions by providing details of the various steps in which cicada hunters proceed from making initial observations, through catching a specimen, and up to the final stages of research including documenting known species in new locations or describing a new species.

Turnhout and Halffman (2024) have discussed the benefits of combining an 'emic' perspective – the insider's viewpoint – with ideas drawn from STS and other theoretical resources. Our analysis draws on our experience as members of the cicada hunter community with differing levels of expertise. With one exception, we are all family members, a father, his two adult children, each who has been hunting cicadas for scientific research purposes since they were children, and their spouses. Each of us holds PhD qualifications, though none in entomology (two in philosophy and the remainder in different scientific fields). Three of our members each have over 30 years' experience, two have around 10 years each, and the most recent member is a novice who has only been on a few fieldtrips and is still yet to net a specimen by themselves unaided. We utilise ideas and methods drawn from cognitive ethnography (Hutchins, 1995) that are focused on the "multisensoriality aspects of experience, perception, knowledge, and practice" (Pink, 2015: xi). In particular, we adopted an apprenticeship method (Downey et al., 2015) in which the relative inexperience of some members of the team was an 'ideal site' from which to draw out a variety of key intertwined social and cognitive features that would have otherwise been opaque. In doing so, we demonstrate that cicada research is novel compared to similar kinds of entomological research, such as lepidoptery. This is due in part to the particularities of the lifecycle of the cicada but more importantly it is due to the place and significance of 'sonic skills' involved in knowledge production (Bijsterveld, 2019). To successfully catch an individual cicada requires a range of learned cognitive practices – patterned habits of embodied activity involved in knowledge making (Menary, 2018; Roepstorff et al., 2010; Solberg, 2021).

A second key contribution of this paper is the documenting of novel sonic skills. Skilled perception in scientific inquiry requires extensive learning (Goldstone and Byrge, 2015). Much work on skilled perception and embodiment in science focuses on the visual domain (e.g., Alač and Hutchins, 2004; Goodwin, 1994). Focusing on auditory perception is important to show that other senses are also crucial in how we engage with the world in scientific reasoning in specific contexts (Supper, 2016). Bruyninckx and Supper (2016, 2021) have documented the increasing interest in the auditory aspects of tacit knowledge in scientific communities. Interest in these 'sonic methodologies' looks at the ways in which sound technologies are used in complex contexts. For example, how geologists can make inferences about subterranean phenomena, such as underground oceans (Bijsterveld, 2019), the development and refinement of recording apparatus in tracking and documenting birdsong (Bruyninckx, 2018; Hunter, 2023; Lorimer, 2008), and ultrasound equipment in bat detection (Mason and Hope, 2014). A second area of interest in sonic methodologies that overlaps with the former set of concerns, but which is in some ways distinct, are the material practices of expert listening, such as bodily skills – following Bijsterveld (2019) we refer to these as 'sonic skills'.

With some notable exceptions, such as the aforementioned work on birdsong, much work on sonic methodologies in STS tends to focus on lab work and on recording devices or other equipment rather than fieldwork (Bruyninckx and Supper, 2016, 2021). When cicada hunting in the field, the hunters rely almost solely on their auditory senses for triangulating and identifying specimens. Furthermore, unlike listening for birdsong, skilled listening is only one step in taxonomical identification. Sonic skills in cicada hunting are not an end in themselves but a means to an ends – viz., the aim is not just to be able to identify by sound differing species but also to be able to locate them by sound sufficiently to get close enough to catch them. Phenological knowledge of local and regional cicadas (what to expect where and when, aided by studies of stored museum specimens, publications, and social media) must be combined with skilled auditory perceptual capacities. One "must listen with one's whole body" (Supper, 2016: 76) in order to identify species based solely on their distinct call patterns (what we call discernment) and triangulate individual cicadas against the sonic barrage of a chorus centre – where large numbers of cicadas make overlapping call patterns as a form of sonic camouflage or perhaps mating frenzy – so that it can then be captured for taxonomical identification and documentation. As we will show, this is a very challenging task and leads to features of sonic skills and social practices which are different from other cases of sonic skills in the literature. Combined with our focus on local epistemologies, the challenges and context give rise to, as Hunter (2023: 6) puts it, "particular, skilled bodies embedded in particular, complex places that produce ecological knowledge".

The paper is structured as follows: In next section we outline the main factors that make cicada hunting in Australia particularly noteworthy in comparison to other parts of the world and to other methods in entomological research. Then we move on to detail how cicada hunters choose an area of interest and begin a hunt – particularly the emphasis on searching for interesting call patterns. This is followed by an account of the sonic skills: how hunters triangulate individual cicadas by their call pattern. Once an individual cicada has been triangulated, the final stage of a hunt is the netting of the target specimen. This is a challenging affair and often ends in failure. If a hunt is successful, then the experts engage in identification and analysis. Finally, we discuss how the identification process is coordinated in the community and provide details on how this information is utilised – including the laborious nature of discovering and describing new species.

Cicadas in Australia

Species of cicadas are found on every continent with the exception of Antarctica. Where cicadas are found, they are often found in large – and loud – numbers. The reason for this is that cicadas spend most of their lives underground, only coming above ground at the end of their lifecycle to mate and, as a result, they typically emerge with synchroneity from egg batches in order to ensure their brief time above ground (typically in the scale of a few weeks) corresponds with the maximum number of other individuals from their species to optimise successful reproduction. The "call" or "song" of males is primarily used to locate potential mates and so during this time famously large numbers can be heard in a restricted location, or smaller numbers of males may produce short calls while moving frequently.

Despite their emergence numbers and their widespread distribution as a superfamily, cicadas are heavily localised when it comes to global species distribution. North America has enormous emergences of individual cicadas known as "periodical" cicadas which emerge in 13- or 17-year rotations that are predictable and loud enough to justify the existence of websites to assist in planning outdoor activities (such as weddings and graduations) during these years (Cooley et al., 2009). Though both extremely numerous and disruptive, periodical cicadas are made up of only seven species of the *Magicicada* genus.[2] Across the Atlantic, Europe as a whole contains only 53 species, and the British Isles is home to only a single species (*Cicadetta montana*) which has not been recorded since the 1990's (Pons, 2020). It is estimated that Australia has around 500-800 described species and likely more than double that number of undescribed species (Corbin and Corbin, 2022; Emery, 2020). Because of its long continental isolation and diverse habitat, Australia also has uniquely unusual species such as *Tettigarcta crinita,* the Alpine Hairy cicada which is uncharacteristically nocturnal, exothermic, and emerges in atypically cool climates and seasons (Moulds, 2005). This makes Australia particularly interesting as a cicada environment, especially now that areas rich in cicada fossils have been documented (Moulds et al., 2022). Our collective understanding and knowledge of cicada species in North America is rather extensive, in contrast, we have a limited and slowly expanding knowledge of the species which inhabit Australia.

Whilst the disparity in global species numbers is a contributing factor in our relative understanding of the cicada species in any environment, a larger factor here is funding and limited expertise. Australia has numerous small, inconspicuous, and quiet species that without prior knowledge are generally unknown and go unobserved to most people. Many Australians think that there are very few species of cicada and that they are mostly large, all roughly the same size and shape, altering only in colour and not sound.[3] The number is far greater, with the actual number only an estimate, as there is no 'official' count or central database which precisely tracks described numbers[4]. Furthermore, considering already described species, there is much of their ecology that we are still unsure about. For instance, the conditions and drivers for emergence patterns and geographical distribution of species are relatively unknown except for some plant preferences and climate. Whilst our understanding of Australian cicadas is increasing, especially with the increase in citizen science submissions to online biodiversity repositories, there are two further challenges.

Firstly, the cicada hunting community is almost entirely amateur – there are no researchers who are primarily employed by universities or other institutions to conduct specific research into cicadas (as opposed to invertebrates as a whole). One likely reason for this lack of institutional backing is that cicadas have no commercial implications and so there is little capital reward and therefore funding motivation for this research. The cicada hunting community is consequently an example of 'little science' as opposed to 'big science' (Solla Price, 1963). Researchers conduct their investigation with little funding, resources, or time, and this obviously greatly curtails the extent of scientific work they can engage in. These issues present challenges that place a heavy burden on members of the community. There are, however, other forms of motivation driving this research. The authors of this paper can attest to the joy of discovery (also see Ellis, 2011), the challenge of the hunt and the feeling of relief and reward with a catch, even the competitive drive between members of the team.[5] Since many of the team members are related, and many members began searching for cicadas as children, this competitive edge is often explicit. Nevertheless, conducting scientific inquiry on a shoestring budget also necessitates a number of interesting innovations, such as engaging in citizen science (Emery, 2020; Greenville and Emery, 2016) and the utilisation of social media.

The second major reason why we know so little about Australian cicadas is because, taken as a whole, they are quite simply elusive, ephemeral as adults, unpredictable regarding emergences, difficult to catch, and inhabit terrain that is often hard to access. Therefore, they are difficult to document and study.[6] This difficulty is perhaps best seen by contrasting cicada hunting to other kinds of entomological field research. For instance, lepidopterologists can use seasonal flowering patterns to inform them of where to look for particular butterfly species (e.g., Finch et al., 2021). In contrast, cicada emergences do not pattern with floral emergences, but rather with altering combinations of elements such as warmth, plant sap flow, and rain. So, knowledge about possible plant or bushland preferences are not always accurate determinants to pin down precise emergence times or locations and instead physical field time is required to confirm emergences (often informed by stored specimens or internet postings). The outcome of this is that cicada research involves substantial travel as well as time and capital (see, Corbin and Corbin, 2022). Entomologists in several other specialisation areas are able to use pheromones or floral odour blends as lures for certain insect species, notably moths and butterflies as well as many beetle species, as well as passive traps such as the malaise trap (e.g., see Kristensen et al., 2015); but these are not viable strategies in cicada research. There is only one lure that can attract cicadas and that is 'light trapping', where a powerful light or series of lights is placed on a large white sheet. The bright lights at night can be an insect attractant, as can be seen at any park or other location which has night-time lighting. Light trapping is a common tactic for many invertebrate species (e.g., Rice et al., 2017). However, not all cicada species or cicada sexes will come to light and, depending on weather conditions and moonlight, those that do will not come reliably. We do not often use light trapping in our own fieldwork as it is rarely effective (one typically spends their night shifting through the thousands of moths and other insects that all attracted to the light trap) and only where incidental lighting is found in a target location (for instance in public restrooms, parks, or reserves) rather than intentionally brought and set up lights.

Cicada research is consequently a 'manual' and often opportunistic affair, in that it depends on the active, embodied, and tacit skills of the cicada researcher themselves rather than on abstract technological or propositional knowledge-based collection strategies. This is a process best categorised in hunting terms where the individual perception and stalking skills of a researcher become paramount in the research process

(Corbin and Corbin, 2022; see also Lorimer, 2008 for further discussion of field researchers self-ascribing their work as 'hunting'). In what follows, we outline this hunting process to elucidate and document the tacit knowledge involved in answering the question: 'how do you catch a cicada?'

Establishing an area of interest and beginning the 'hunt'

Cicadas only emerge above ground for short periods of time each year in the final stage of their life cycle. In Australia (unlike the 'periodical' cicadas of North America) they are not known to emerge in predictable or consistent patterns. This presents the first and most obvious challenge for the researcher, with long-term dedication needed for repeated field studies and collection. Long fieldwork hours are also demanded in the harsh conditions of the Australian bush, where summertime temperatures frequently reach 40 degrees Celsius, and researchers must be mindful of snakes and a range of biting insects. In other words, cicada researchers need to be very dedicated to their work. The second challenge is that most Australian cicada species are very small (<30mm long) and well camouflaged, making them challenging to visually locate (see figure 1). Despite the often large emission of calls – both in terms of numbers of calling cicadas (referred to as 'chorus centres'[7] (Williams & Simon, 1995)) and overall audio volume – they can also be very hard to pinpoint aurally without substantial training and experience. This is perhaps unsurprising, as cicada songs, in addition to acting as a mating call, are likely to have evolved under selection for their ability to deter predators, due both to simply their volume (Smith and Langley, 1978) and for their effect of auditorily "masking" an individual and blending their call into a chorus preventing effective triangulation[8] (Shieh et al., 2012; Ishimaru et al., 2022). Combined, this presents researchers with a challenging epistemic environment. Yet, despite these difficulties, the cicada hunting community successfully locates populations of unique cicada species and effectively tracks, catches, and studies individual specimens in preparation for taxonomic description.

To begin, cicada researchers need to identify a location to target a range of cicadas or specific species. We approach this in several ways. Firstly, one can visit local State museums or the Australian National Insect Collection (ANIC; Canberra) to check labels on stored specimens to provide a previously successful time and location. Secondly, we use a citizen science app, iNaturalist, which allows for crowdsourcing and massive collaboration in the collection of data. Members of the public with this app can take photos and audio recordings of natural phenomena they deem to be of interest but do not necessarily know what it is. Other users of the app can then provide species details. Users of the app gain points for original posts and for providing labels and information on other posts. Gamification as a way of motivating participation in citizen science projects has been examined in a number of contexts (e.g., Bowser et al., 2013). Given that iNaturalist has over 1.4 million users globally, and Australia is one of the largest contributors with over 1.6 million observations made by over 27,000 users (Mesaglio and Callaghan, 2021), the platform is proving to be useful for the collection of data points. Our team uses the iNaturalist app to obtain information on phenology, locations, species, and audio recordings. This sometimes involves contact with the original poster on the app to secure specimens and recordings or gather more specific details for site visits – especially if the sighting was off-road

Figure 1. An example of cicada camouflage.

and deeper into the bush. By using iNaturalist, we are able to collate observations over a much greater distance and area than could be physical covered by the few team members in the limited time they have. Thirdly, researchers may follow tips from other general entomologists or park rangers.[9] Finally and most commonly, we may simply drive around in heavily bushed areas, heathland, desert, or undisturbed riparian tracts along watercourses (typically next to or near national park or public land) slowly with the window open listening carefully (Corbin and Corbin, 2022). This final approach may be conducted at intervals in a target area that has been productive in previous years, or this could be a new and unknown area which is being surveyed for the first time.

Regardless of how the area is selected, the first step in catching a cicada is almost always *hearing* a cicada.[10] Cicadas produce songs made up of repeating call patterns which are specific to their species. Song therefore provides an alternative basis for scientific research practice to those commonly used for other invertebrates. Cicada researchers must travel large distances either by car or by foot, simply listening until they hear a cicada which is novel or worth the effort to catch as a locational record. This entails that acquiring and mastering sonic skills are crucial for cicada hunting.

Since cicadas are often very hard to catch, substantial time is invested in catching them once a population has been found. Consequently, one of the first questions a cicada hunter must ask themselves on hearing a call is how much time to invest attempting to locate and catch the cicada they hear. Therefore, one has to listen and see if it is "interesting", by which we mean whether it is the call of a new or little-known species, a known species but in an unusual area, or perhaps simply of interest to the cicada hunter. Bijsterveld (2019) labels this the 'why' mode of listening – the purpose of listening. In turn, these motivations, combined with training, shape the hunter's auditory attentional patterns and allows for greater discrimination and parsing of the perceptual array (Goldstone and Bryge, 2015).

Only male cicadas sing or call,[11] so initially the cicada researcher is limited to tracking males. Their call is produced by timbals, a membranous structure containing 'ribs', which are bent and buckled at high frequencies by muscles (Fonesca, 2013). Timbals may be exposed (Subfamily *Cicadettini* Buckton) or covered (Subfamily *Cicadinae* Latreille). On the underside of the abdomen are opercula, colloquially referred to as 'drums'[10], and together with rhythmically flexing the corrugated structures of cicada abdomens which act as a resonance chamber, all contribute to vibrating the air rapidly and amplifying the sound significantly (Pringle, 1954; Young and Bennet-Clark, 1995; Ewart and Popple, 2001). Knowledge of the bioacoustics of how cicadas produce their call pattern is crucial since it is these features that differentiate them from the calls of other insects in the bush. Cicadas of many species are attracted to the songs of their own species, and males are stimulated to call by increasing temperature in the mornings and by the calls of other males. For those species, this creates 'chorus centres' of dense population of potential mates (Williams and Simon, 1995). These chorus centres often overlap, with multiple species calling in the same place at the same time. This requires the hunter to be able to specifically focus their hearing on the single target species. We refer to the ability of a cicada hunter to identify a cicada species based solely on the call pattern as 'discernment'.

All cicada call patterns are unique to their species, and therefore a species can be identified by its call alone. Consequently, to judge if a species is "interesting" or not, significant numbers of cicada calls must be recognisable to the researcher. Cicada hunters must learn, memorise, and recognise songs for the cicadas that are common in their region and their interests. Like other scientific communities in which listening practices are crucial, for example in ornithology (Bruyninckx, 2018; Hunter, 2023; Lorimer, 2008) and in hospitals (Bijsterveld, 2019), agents must master the terminology, coding schemes, thought styles, strategies, and practices that have been devised to delineate the objects of inquiry (also see Goodwin, 1994; Latour, 1987). To assist cicada hunters in the learning of calling songs, descriptive and recognisable terms are documented in written resources, covering the volume, pitch, dynamics, frequency and duration, and the tone, e.g., 'metallic', 'yodelling', 'rattle', or 'syncopated'.

Additionally, for non-verbal communication of cicada call patterns (particularly important in the field during a hunt), cicada hunters engage in a form of 'data karaoke' (Supper, 2016) – using onomatopoeia for phonetic imitation, e.g., "Clip-clop", "buzz", "tick", "zip", "zop", etc. 0.[11] Not only can this be for communicating between team members on a particular hunt, it can also act as a form 'instructional nudge' (Sutton, 2007) in which a hunter tries to direct and steer their own auditory perception and acts as a memory aid. Visual representations of the calling songs are also used as 'sound diagrams' (Bruyninckx, 2018) for educational and communicative purposes, for example the use of dots, lines, and squiggles accompanied by descriptive words such as "ee-ay", "orrr", "shic", and "dee" (see Figure 2) and the more conventional waveform plots of spectrogram (Emery et al., 2015). It is also useful in learning and teaching call patterns to compare them to known sounds. For example, the pattern of the Floury Baker (*Aleeta curvicosta*) could be communicated to a novice by likening it to the sound of maracas shaking and getting increasingly louder, or – as appropriate to the intended audience – it could also be likened to the gradually increasing speed of clapping given by the crowd at a cricket match as the bowler runs up to deliver their ball.

Even for experienced cicada hunters, the identification of calls can be difficult and confusing. This is particularly the case for the members of the team who started hunting for cicadas as adults. At the start of a new season, they will point in the direction of a 'cicada' call only to receive the disparaging news that it is a cricket, katydid, or other non-cicada species. As with many other cases of sonic skills and auditory perceptual learning (e.g., Bijsterveld, 2019; Bruyninckx, 2018; Goldstone and Byrge, 2015; Lorimer, 2008; Irvine, 2018; Roepstorff et al., 2010), the learning and memorisation of cicada songs is possible through repeated exposure to them. By learning a variety of call songs and having points of comparison, differences become apparent. Once trained to recognise a cicada call, a bias is developed whereby people become attuned to its presence and in fact become practised to hear it over the ambient soundscape.

In the field, researchers often use recording devices to not only document cicada calls but

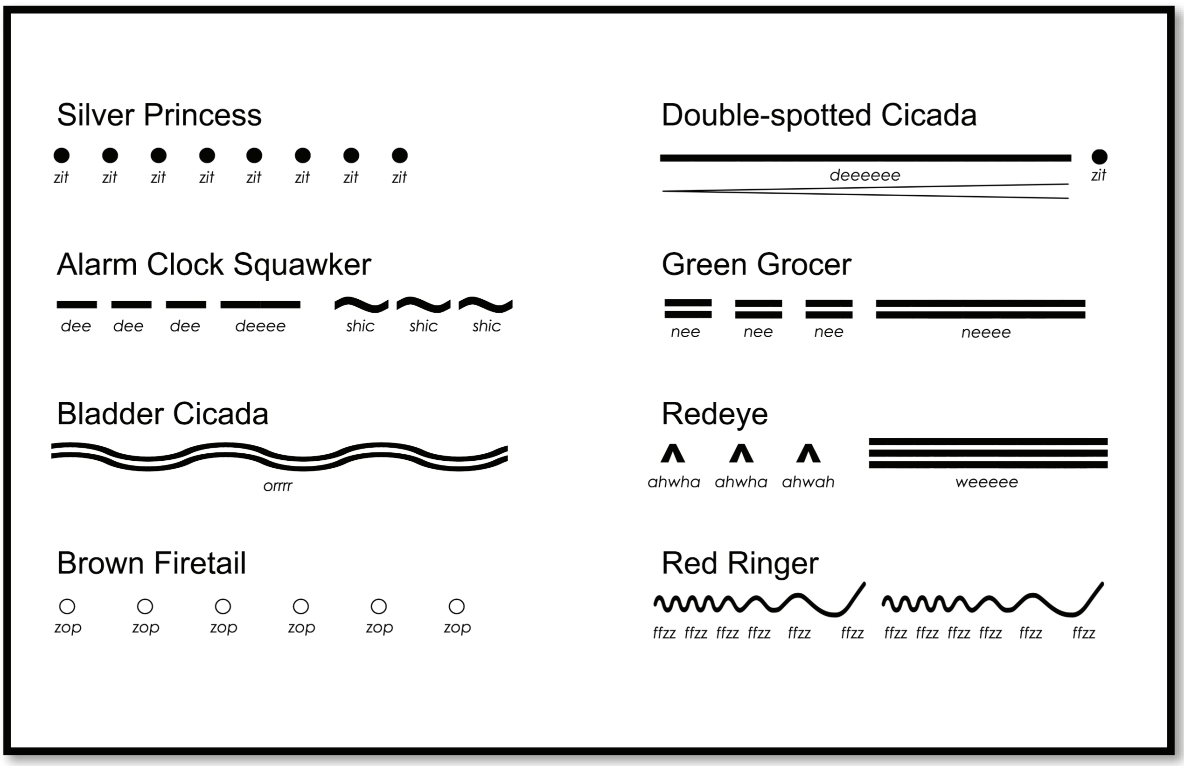

Figure 2. A selection of visual representations of cicada call patters, reproduced with permission from Emery (2020).

also to share amongst each other to confirm the species origin of a call. Improvements in the portability, durability, and fidelity of recording equipment has increased the extent to which recordings are seen as a crucial tool in the arsenal of the researcher (Vallee, 2018). As Bruyninckx (2018) notes in the case of the science of birdsong, improvements in both recording equipment and analytical techniques, such as spectrograms, were a major driver in the field in coming to terms with the complexity of the phenomena of bird song. Some practitioners even went as far as comparing spectrograms to the invention of the microscope (see Bruyninckx, 2018:123 for discussion). For cicada research, these inventions have altered publication practices about what details are included in scientific publications. Between cicada seasons, due to lack of regular 'practise' in the off season, hunters do forget some of the call patterns and a simple refresher by listening to a recording is often sufficient to "jog" the lost memory. Playback of recordings in the field may also be used to encourage otherwise silent males to sing. Lorimer (2008) and Hunter (2023) have documented the use of recordings to elicit a response in the fieldwork involving birdsong to varying levels of moderate-to-high success – they can be used as a lure in some cases but can also confuse other fieldworkers. But in our work with cicadas, the success rate is much lower. If cicadas are not calling then a hunter is typically standing still and merely waiting, so playback is only attempted in the absence of an alternative. While songs identify species, they do not provide any other information on morphology or behavioural ecology to aid capture for descriptions, which is why they are only the first step in a larger process. Sonic skills are needed to move from identifying a species to locating a specific individual within a group of the same species that can then be stalked and captured.

Once a researcher has established an area of interest, they need to stalk a call and get closer to an individual cicada. Cicadas range from as little as 10 mm in forewing length (for example, *Punia minima*) to 70 mm (such as *Thopha saccata* with a total wingspan of up to 200 mm). However, typically, larger cicadas are not as "interesting" from a research perspective as smaller ones, the reason being that larger cicadas are louder and therefore more noticeable, are easier to see and catch and so naturally, much more is known about them. Unsurprisingly, larger cicada species produce the loudest sound, which is multiplied by their en masse emergences in chorus centres. Larger cicadas also survive for longer periods of 3-8 weeks as adults (e.g., 'bladder cicadas' and 'black princes') compared with 1-2 weeks for many smaller species. As well as their diminutive size, many cicada species spend their adult lives high in trees. For these and other reasons (thick surrounding brush or dense host plant, dynamic with frequent movement, predator avoidance strategies, etc.), cicadas are extremely difficult to locate simply by relying on eyesight and so the cicada researcher must rely on their auditory perception. This is the case in initially identifying population centres, but also in tracking individual cicadas. Without these auditory signals the researcher would not be able to begin stalking towards a position cued by the call of a target species.

Expert Auditory Perception, Triangulation, and Netting

Once a hunter has identified a target location and species, they must then identify a target individual that they can then stalk, triangulate, visually identify, and ultimately net. This process starts with a range of interconnected sonic skills.

Adult male cicadas are primarily singing to attract females to mate. For the larger species, females fly to the males in response to their singing. More typically for smaller species, males move constantly and sing at rest or call when in flight, waiting to hear wing flicking from resident females that signal their readiness to copulate. As such, males typically move frequently, flying from tree-to-tree or branch-to-branch listening for a response from a potential mate. This frequent movement means that the researcher does not have boundless time to hear, visually identify, get close to, then swing a net and catch a cicada.[12] Researchers must move quickly if they are to locate and catch an individual.[13] Cicadas have good eyesight, and sense movement or vibrations, so they are aware of threats in their environment. And this is an important point of difference with some other forms of fieldwork in which the researcher will aim to achieve a form of neutrality (cf., Alcayna-Stevens, 2016). Cicada researchers are hunters and so we do not see ourselves as neutral observers and are not trying to get cicadas to habituate to us, we recognise that we are predators and relate to them as such. Fast, jittery, or obvious movement will elicit a threat response and the cicada will either fly away, drop to the ground pretending to be dead, walkaround the other side of a tree away hiding from the hunter, or simply stop singing and remain still. The researcher quickly learns these behavioural idiosyncrasies and adjusts their approach and capture technique to counter. Mason and Hope describe this as 'attunement' – an "embodied sensitivity to particular non-human differences" in movement (Mason and Hope, 2014: 108). They argue that this is essential for certain forms of scientific fieldwork. We see examples of this in our own fieldwork: when hunting in the early morning before the day warms up and cicadas are only starting to sing, they are typically on the sunny side of trees and shrubs to warm up faster. Similarly, in windy weather cicadas will move around plants to have the branch they are sitting on to protect against winds. Because of these environmental factors and behaviours, hunters must also be listening for the 'dulling' of a call, indicating that a cicada has hidden itself behind a physical structure out of direct sight. As such, the hunter-hunted relationship is one in which, rather than being a neutral observer, the cicada researcher enters into the world of meaning of the cicada (also see Alcayna-Stevens, 2016).

Large emergences of cicadas create a cacophony,[14] which is both an effective species attractant and a deterrent for predators. This has three main outcomes. Firstly, the chances of mating are maximised. Secondly, the sheer volume and combination of large numbers of individuals generating calls can cause auditory discomfort and even pain – the threshold for pain in humans is around 120 decibels, and over 90 decibels can cause damage following extended exposure (Rodaway, 1993). Several species of cicada can generate volume of these intensities (e.g., *Thopha saccata* and *Cyclochila australasiae*). The cicada's own hearing organs (their 'ears', technically termed tympana) collapse to protect it from the damage that would otherwise be caused from the decibel level they achieve (Hennig et al., 1994). Thirdly, cicada chorus can resonate, disorientate, and mask the call signature of a specific individual. If one individual cicada is calling, it is not overly challenging for a cicada hunter to track. If many are calling, it is far more difficult to isolate any one individual. In this way, chorus centres act as sonic camouflage. Although a chorus makes a population much more obvious, it masks the individuals within it in much the same way that certain fish are simultaneously more visible yet more protected from predation while within a school. However, cicadas in populations are constantly moving (particularly for smaller species) to counter competing sounds that may detract from mating signals, many co-locating cicada species either call sequentially, call at different times of the day, or cluster together to avoid confusing signals. Awareness of this and other behavioural traits which impact song production is crucial knowledge for cicada hunters[15]. But, without a specific target one cannot reliably track an individual and get close enough to visually identify and ultimately net it, much like sharks and other aquatic predators are challenged by schooling fish (Neill and Cullen, 1974). In these instances, it can be difficult to determine the number of cicadas calling. There could be one very loud cicada, or several added together in synchrony. Or simultaneous but staggered and not in sync. Thus, one of the main sonic skills cicada hunters must learn is the ability to disambiguate call patterns and pick out particular individuals. The ability to determine patterns is what we refer to as discernment, and the ability to pick out a single cicada among many, or to identify the number of cicadas calling in a given location, we refer to as enumeration.

Discernment and enumeration are a rarefied form of resolving the challenge of 'auditory scene analysis' (Bregman, 1994). Auditory scene analysis, often colloquially referred to as the 'cocktail party problem', is a common challenge that all humans face in any environment in which they are listening to a specific sound amidst the surrounding other auditory phenomena, for example listening to a conversation amongst loud background chatter.

I.e., it is the task of focusing on a certain set of auditory events (streaming) and disambiguating them against the noise of the background. Some sonic environments have a very poor noise-to-signal ratio (lo-fi soundscape), others have a much better ratio (hi fi soundscape) (Rodaway, 1993; Schafer, 1977). We can easily intuit the difference by thinking about trying to listen to a conversation in a quiet room with one other person (a hi-fi soundscape) compared to carrying on the same conversation on a busy street or in a busy café (a lo-fi soundscape). Much greater effort must be put into streaming in a lo-fi soundscape. Cicada hunters are sometimes confronted with extremely lo-fi soundscapes – the walls of noise produced by chorus centres or other cicada species – and so discernment and enumeration can be very taxing.

It is important to note that enumeration is not merely "counting by ear", as Lorimer (2008: 390) puts it, by which one is taking an individual call as a data point for a census. Rather, through enumeration, the hunter is aiming to estimate the number of calling insects in the same location so that they can then go about isolating and picking out a single individual – which is a much more complex task. The key element in enumeration as a sonic skill draws on the call pattern – that each species has a distinctive rhythm and duration to their call based on the bioacoustics of the insect. This can be used to parse overlapping but nonsynchronous calls. The hunter can begin to try and localise this individual and triangulate their location. This involves sophisticated abilities in spatial hearing (Blauert, 1996). It is important to note that although cicada hunters need to be careful in their movements in the bush, not only because of snakes and other hazards of the Australian bush, but lest the hunter scare off their target. As such, movement is also a crucial part of skilled listening. Cicada hunters are not passively listening but actively engaging with the environment. Despret (2013) notes that field reports rarely mention the body of the scientist. But in cicada hunting the embodied aspect of sensing is crucial: they are "listening with their whole body" (Supper, 2016: 76). By moving, we alter the signals in the call patterns – by tilting or turning the head, taking hats off, cupping the ear to improve directional sound isolation, waiting for breezes or unrelated noises to stop, standing taller or squatting down, and moving to different locations whilst stalking (also see Lorimer, 2008). By actively probing the local sonic environment in this way, cicada hunters make it much easier to enumerate and triangulate: establishing the direction of differing individuals which are making call patterns from differing directions. Once relatively sure of the cicada's position, hunters can then proceed to close in on the target individual. The composite of these sonic skills, the mental library of call patterns, forms of embodiment, and particular patterned practices that govern their interplay can be considered a community of practice with a 'local epistemology' – a particular active way of knowing (Chang, 2022; Longino, 2002). For cicada hunting, it is important to emphasise that the local epistemology is centred around knowing how to listen (also see Bijsterveld, 2019; Bruyninckx and Supper, 2021). Not only being able to identify an animal by their call, often in the challenging epistemic conditions of lo fi soundscapes, but also the ability to estimate the number of individuals making a call so that one can be triangulated. This gives cicada hunting a unique sonic methodology tied to the particular material, social, and cognitive conditions in which they are emplaced (also see Hunter, 2023).

Given that cicada hunting is very challenging, we sometimes work together to spot the target once we have established the potential location of an individual. When working together, there can be a division of labour to have a greater chance of catching a cicada. These collaborations are organised spontaneously based on where particular members of the team are in relation to the target. But tasks are also sometimes delegated based on a person's abilities. For example, one member of our team is particularly deft at catching cicadas with her hands. So, in cases where a net cannot be used, she is often called upon to take the lead. In other cases, when stalking a target together, this involves hunters moving quietly and slowly around different sides of trees and shrubs, standing still when the cicada is silent, and communicating to one another through hand signals such as pointing towards the cicada or raising a hand to halt movement.

But whilst being able to pinpoint the location of a particular individual in challenging circumstances might be an impressive auditory feat, we must place this epistemic activity within in its context: the primary goal is to catch a cicada. Knowing how to hear a cicada is embedded within what Chang (2022: 16) calls the wider 'epistemic activity' – "a system of practice is a network of activities that function coherently together" in the acquisition, assessment, and use of knowledge towards a goal – in this case of being able to catch a cicada. As Bijsterveld (2019) notes, we can differentiate between several distinct 'modes of listening': the why, the how, and the what. The how, or way of listening, is both analytic (in terms of breaking down the sonic information into finer details of species type, and individual location from the wall of noise), but is also interactive insofar that triangulation requires that cicada hunters move through the environment and manipulate the sound source to establish location in acute spatial hearing. The why, the purpose, of sonic skills in cicada hunting is ultimately to be able to pinpoint and triangulate an individual specimen.

The effective use of a butterfly net combined with several connecting aluminium poles, sometimes extending to three or four metres in length, can be critical to a successful catch for cicadas that are flighty or typically occur in tree canopies. When it comes to swinging a net to catch an individual on a tree or shrub, some members of a team will act as spotters. If the primary hunter with the net misses (a frustratingly frequent occurrence), the spotters help to see where the individual flies to and lands. On occasions where a cicada is resting in a fork of a branch or protected by numerous lateral branches, a second person will attempt to coax a cicada to fly from a tree into a nearby open net, by using a pole or second net to touch the branch the cicada is resting on and spook it. The addition of a second net may also increase the chance the cicada will take off and fly into the net. With every extension pole added, the harder it becomes to control due to weight, gravity, and inertial resistance from the pivot point, requiring more upper body strength. Some members of our team are much more adept at this, but divisions of labour are not always straightforward because there is a competitiveness between members to be the one who makes the successful catch. Attempting to catch a cicada several metres above ground in a tree canopy requires patience, stability, and strength to guide the net between branches to not disturb the cicada and prevent the net from sudden movements due to snagging the netting on twigs or unexpected wind gusts. In addition to physical prowess, using a net is a cognitively demanding skill requiring a wide body of species-knowledge. Depending on the species, particular cicadas will behave differently to threats – and humans trying to put them in a net certainly counts in this category. When one tries to get a cicada, knowing the behaviour pattern is important for a successful catch. Some species, such as the 'Smokey Buzzer', *Myopsalta waterhousei*, or 'bladder cicada', *Cystosoma saundersi*, will often drop at the sight of a net and feign death. Species commonly found in heath, shrub, or grassland communities, such as *Diemeniana euronotiana,* often do not fly far before landing again and can be tracked by eye in some instances. Others, such as *Yoyetta grandis*, will more typically fly to a nearby tree. Other species do not fly away and stay in the tree they are in; *Auscala spinosa* ("creaking branch cicada") will often hide themselves in the grooves of their favoured ironbark trees, making net capture almost impossible. Other species, such as *Atrapsalta furcilla*, will often simply walk around the branch, while *Chelapsalta puer*, will remain stationary in the midst of their *Cassinia* host plant, leaving a net to bounce away unproductively. Mastering and appreciating these idiosyncratic behaviours is not propositional but is instead learned through much gruelling trial-and-error on behalf of novices, with many hunts ending in frustrating failure. This is where the active knowledge and motivations of cicada hunting goes beyond the joy of recognition present in other forms of naturalist communities (Ellis, 2011) and into the thrill (and frustrations) of the hunt.

The cicada behaviour and position on vegetation also lends itself to the method of approaching it with a net. Oftentimes a cicada resting on a tree trunk or primary branch can be coaxed into an open net by using the round metal frame to slowly slide up under the cicada before sweeping the net away from the tree as the cicada takes flight. By contrast, cicadas resting on thin branches of trees, shrubs or grasses can be caught by quickly sweeping the net in a smooth motion that often captures both the cicada and vegetative material as collateral. In either case, both methods require consideration of several factors pre- and post-netting of cicadas. Firstly, the direction of the net should consider wind direction and, where possible, position the open face of the net to the prevailing wind. This ensures that the net remains open to increase the likelihood of the cicada been caught or blown into the base of the net, making it less likely to quickly escape. A net position with the wind effectively creates a mesh barrier that a cicada may contact and then fly away from. Secondly, consideration must be given to the vegetation surrounding the cicada and the risk of snagging, ripping, or damaging the net if attempting to sweep catch. Some woody shrubs and herbaceous plants have spines or thorns that will rip the mesh net rendering it useless. Finally, regardless of how a cicada is first netted, once ensnared the hunter must then continue to sweep the net away from vegetation with force to ensure the cicada is 'pushed' to the bottom of the net before turning the poles in their hands through 90° to fold the net over itself around metal frame to prevent the cicada escaping. This action is difficult when using multiple poles or in strong winds, but continually sweeping the net back and forth while trying to fold the mesh over the frame should eventually be successful. A less skilful but effective technique is to swing the sweeping net straight down onto open ground and then holding up the base of the net to trap the cicada by encouraging it to fly vertically. A field diary with entries outlining details of daily catches is an integral reference to the actual specimens captured, seen, or recorded.

Identification and describing new species

If the hunters are successful in making a catch, then the next step is to go about identifying what it is that we have caught. Since members of many cicada genera are morphologically similar, song provides the initial evidence that a particular cicada is different from other like species. For description, a minimum of six males (singing the same song and providing a verified series to accommodate variations across the species and confirm distributions) and several females are usually needed. We often consult with one another through discussions either in person or via apps and photo-sharing sites, where photos or recordings of the individual and/or its song may be uploaded to enlist the help of those who are more experienced, to postulate its novelty. While it is possible to determine some species from photos or song recordings online, the actual specimen(s) is crucial for definitive identification. One exciting prospect is if it is a new species – this what drives members of the team to spend the many hours in the hot Australian bush being bitten by mosquitoes and leeches. If it is a putative new species, then the next possibility becomes one of taxonomic description after a series has been collected, dissected, and compared against extant described species. When new specimens are captured, live individuals may be photographed. Then the three right legs may be removed and placed into absolute ethanol for later DNA isolation and analysis, before the specimens may be pinned and "spread" and dried for around a week. Meanwhile, labels containing details of location (with GPS), date and plant data (and perhaps catalogue numbers) are prepared and attached to each specimen for later reference. Specimens are then stored in insect- and rodent-proof drawers or containers prior to additional photography for publication.

A key element of this descriptive process is the establishment of converging lines of evidence (Hacking, 1984) that are robust in Wimsatt's (2007) sense: i.e., the evidence is drawn from measurement methods and procedures that involve differing modalities and techniques (also see Chang, 2004, 2022). Once sufficient individuals are available, and this may take many seasons (where seasons are years of emergences), then holotypes are described before these and paratypes are deposited in appropriate collections and catalogued (especially those holotypes and paratypes in museums) for future reference and to reduce risk of loss. Catching mating couples is particularly valuable to ensure the identity of females, since mating is species-specific and females are harder to find as they do not sing. Females often exhibit significant sexual dimorphism in colour and traits (i.e., look very different to males of the same species) and even have physical differences between specimens.[16]

Historically, cicada publications did not include song analyses as appropriate field equipment was not available or cumbersome (e.g., Moulds, 1988). However, as more versatile, reliable, and sensitive technology allows more precision and clarity in the field, song recordings of the males are becoming increasingly analysed for inclusion in recent descriptions (e.g., Emery et al., 2015). The changing publication practices here speak to the increasing and central role of sound and listening in this specific branch of entomological research (also see Vallee, 2018). Song was highly likely used to find the species in the first instance and is species-specific, thus offering a complementary taxonomic characteristic for species differentiation. A series also provides the range of measures and morphological variations to give greater accuracy and rigour to descriptions as well as covering species phenology. As such, here we have a case in which sound is not relegated or secondary to visual information, but is a primary source in the production of scientific knowledge (also see Bijsterveld, 2019).

In addition to analysis of the song characteristics, the other species-determining properties of the specimens are investigated. These include the song-making apparatus, the timbals and opercula, and the genitalia for mating. These are examined, often dissected, and drawn or photographed along with various views of the holotype male and paratype female (at least dorsal and ventral views of spread specimens). All aspects such as colour, shape, and size of the body parts of the male and female specimens are described (body, wings, legs, and genitalia) and linear measures of body, wings, and widths of head, thorax, and abdomen, across the series is included to establish species characteristics according to prescribed nomenclature and methodology (e.g., Moulds, 2005; International Commission on Zoological Nomenclature, 1999). Also included in the description are features which distinguish the new species (*species nova; sp.nov.*) from others in the same genus. Advances in geospatial technologies – geographic information systems – have transformed practices in insect ecology and made recording, storing, and computing of geospatial data (Liebhold et al., 1993). Modern taxonomical papers are able to more precisely provide GPS plots of where specimens have been found (distribution), and these are presented alongside photos of the habitat and any particulars of plant preferences. Ultimately, morphological features are used to create a dichotomous key to enable a stepwise approach to identification of a cicada's species in a family or genus. Authors select a name for the species and give reasons for their selection (etymology).[17] Then they apply to register the name and species on "The Official Registry of Zoological Nomenclature" (https://zoobank.org/) to obtain a catalogue number which is included in the paper. Following submission, peer review, emendation and acceptance, the description of the new species can be published in the journal.

All of this takes quite some time. For example, Emery and colleagues (2019) recently revised the genus *Yoyetta* Moulds and described eight new species. It took the authors' team over 15 years to catch and record the requisite number of individuals in this case and another 3 years to fully produce the final draft. This demonstrates the scale of time and effort which can be required to achieve and complete this kind of 'little science' research without major funding. However, sufficient specimens and recordings may be obtained in a single productive season if only one new species is to be described. Since authors are writing papers in their spare time (not part of their paid job), it may take 1-2 years to get the description published; longer as exemplified above, if more species are included. But the effort is required to document our precious biodiversity, especially in an era of declining insect numbers in many parts of the world (Didham et al., 2020). A love of nature, being out in the Australian bush (despite the mosquitos and flies), the joy of recognising a call pattern, the friendly rivalry between ourselves and other members of the wider cicada research community, and the thrill of identifying a new species all motivate us to put in this work in the field.

Conclusion

Cicada hunting provides us with a novel case demonstrating the central role of sound and practices of listening in the life sciences, and "the auditory dimensions of making knowledge" (Bijsterveld, 2019: 1). Hunting cicadas is primarily based on the central idea of the call pattern – that each species has a distinctive song – and this guides a range of sonic skills: being able to not only identify species by their song (discernment), but also estimate how many individuals are making a call (enumeration). This is crucial because cicadas use sonic camouflage in chorus centers to disorientate and conceal their location. By enumerating a call pattern, an expert cicada hunter can pick out a single individual and then begin to triangulate them by dynamically moving through the bush. Cicada hunters are not passive observers, but rather listen with their whole bodies, stalking their target, and aiming to catch them in a net for documentation. Cicada hunting fieldwork is gruelling and challenging and often ends in failure, but members of the team are motivated by the thrill of the hunt, the joy of identification, and the possibility of discovering new species. Following the capture of a series of individuals and the recording of their calls from several locations, the process of specimen preparation, storage, and sampling for downstream investigation all are directed to the description and curation of the new species for future reference and conservation. Our account shows that active knowledge embedded in a community of practice is required for producing a taxonomical scientific paper. As the vital starting point, the importance of the call pattern to all that follows in this endeavour, cannot be over-emphasized. Drawing on an ethnographic study of the authors' own practices as cicada hunters, our paper contributes to ongoing discussions in STS scholarship regarding the multimodal production of knowledge in scientific communities.

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Notes

1 For example, *The Sydney Morning Herald:* some cicadas reach "the level of sound a jet makes taking off." https://www.smh.com.au/environment/conservation/as-loud-as-a-jet-taking-off-why-do-cicadas-sing-at-dusk-20211101-p594xe.html (accessed May 17, 2024).

2 It is only these seven species which emerge in precise, predictable broods every 13 or 17 years. Most species do not follow predictable emergence patterns. The emergence patterns involving prime numbers has been debated heavily both in philosophy of science – about whether it constitutes a genuine mathematical explanation – and in philosophy of mathematics – about whether it supports a naturalist-realist position (e.g., Bangu, 2012; Craver and Povich, 2017; Lange, 2013).

3 Anecdotally, multiple members of this team thought this before becoming involved in cicada research.

4 For the most complete current catalogue, see; https://dr-pop.net/cicadas.htm (accessed May 17, 2024).

5 This competitive drive is also found in the iNaturalist community, which contains leaderboards and other gamified ways of measuring success relative to other members. We discuss this in more detail below.

6 Unless otherwise indicated, all subsequent statements in the paper refer exclusively to Australian cicada species.

7 Most entomologists are experts in a specific taxon. One of the present authors knows a great deal about cicadas for example, but practically nothing about jewel beetles. However, he does know a jewel beetle expert, so when he comes across a jewel beetle population he will pass on that information. In a similar fashion, cicada hunters often receive 'tips' of potential locations where "cicadas" (very rarely precise species) have been heard. There is also the exchange of specimens between experts from differing entomological research communities, especially for description or curation.

8 We have added the caveat here of 'almost always' because it is the case that sometimes, despite their camouflage, individual cicadas can be spotted by scanning visually. Cicadas will sometimes go silent (especially if they are wary of a predator) and females do not call. It is also the case that sometimes the best opportunity to catch cicadas is when they initially emerge from the ground in their nymph stage and before they fully transition into adults and begin calling. But this requires having prior knowledge of suspected emergence patterns – both in terms of seasons and locations, But also in terms of potential environmental triggers, such as climate factors.

9 Females of certain species do make audible sound by wing clapping, hitting her wings against her abdomen likely to signify her presence to a potential mate. However, this is typically very low in volume and could not be relied upon to identify population centres or track individuals as songs are.

10 This colloquial reference can be somewhat confusing as the hearing organ of a cicada is termed the tympanum, literally "drum" in Latin and similar in form and function to the human 'ear *drum*'.

11 See also, https://dr-pop.net/ (accessed May 17, 2024)

12 An exception to this rule is when a mate is found, and male cicadas lose their wariness in the "heat of the moment".

13 There are a few notable exceptions here. Some species have a 'courtship' calling song that is slightly different to the normal song, since this can be identified by the researcher in that the cicada may not necessarily fly away immediately. Some species also have an evening/dusk calling song - e.g., the floury

baker and double spotted cicada. The differing call patterns in a singular species based on environmental effects adds to the complexity of the skilled auditory task.

14 American species have been surveyed for over 100 years with Andrews estimating in 1921 that there were upward of 100,000 individuals per acre. In 1937 this number was increased to 1,394,000 per acre (Andrews, 1921; Andrews, 1937). However, no data is available on Australian species. But given the higher diversity and number of species in Australia, we expect it to be different with substantial geographic and temporal variability.

15 Interestingly, this knowledge may be used to one's advantage against wary male cicadas which call in flight, as the hunter may remain stationary and use timed finger snaps or tongue "clicks" to emulate the female wing flicks and attract the flying male to land nearby.

16 A good example of this is the Golden Twanger which has a green morph and a yellow morph.

17 In the cicada hunting community, there are three differing naming systems employed – each suited to varying research interests and requirements. Firstly, there is scientific name. For example, Pauropsalta mneme. The Latin signifier is the standard way of labelling species in Linnaeus taxonomy and allows scientists to place species in clades – diagrams that depict evolutionary branches and determine higher taxonomic properties, such as genus, family, etc. Secondly, there is a taxonomic numbering system, a method originally developed for cataloguing undescribed cicadas numerically for quick reference and organisation (Moss and Popple, 2000). This designation system is used to catalogue and organise specimens in physical and online inventories such as the Web Guide to the Cicadas of Australia (https://dr-pop.net/cicada-list.htm, accessed May 17, 2024) run by Dr. Lindsay Popple. Lastly, there is the common or colloquial name, many of these are extremely colourful and descriptive. For example, the 'Black Prince', 'Greengrocer', 'Floury Baker', 'Masked Devil', or 'Alarm Clock Squawker'. The common name is often used for engagement with the public given that this is the name most widely used. All described cicadas will have one of each of these names.

Lessons from the 'Dark' Side: Emotional Labour and Positioning in Cross-Sectoral Collaborations

Katia Dupret
Roskilde University, Denmark/ katia@ruc.dk

Anya Umantseva
Roskilde University, Denmark

Daniela Lazoroska
Lund University, Sweden

Abstract

Collaboration across disciplines and stakeholders is important in handling complex societal problems. Even if collaborating is acknowledged as contributing toward societal change and innovation, collaborators' emotional experiences during development, consolidation and completion of a given project are underexplored. This article discusses emotional labour in three cross-sectoral collaborations using participatory observations and interviews. It analyses the potentials and pitfalls of focusing on emotional labour that foregrounds collaboration as a dynamic that changes with the development phases of a project trajectory. The study finds that rendering interpersonal dynamics visible may both be a way to gain authority and legitimization in the collaboration but can also be used as a strategy to marginalise others. On the other hand, maintaining the invisibility of emotional labour can also be an expression of power. The obscurity of these complex dynamics makes it difficult to navigate and propose what makes a good collaboration. The paper aims to contribute, from a practitioner-oriented and theoretical vantage point to a more reflexive and sustainable practice and nuanced understandings of collaborative practices in research and at an institutional level, particularly in the field of social change and innovation.

Keywords: Research Collaboration, Work Identity, Emotional Labour, Social Innovation

Introduction

It has become an axiom that we need collaboration to be able to address complex societal issues. But how do participants in cross-sectoral collaborations experience the endeavour? Despite a long history of collaborative inter- and trans-disciplinary research in various interrelated fields such as responsible research and innovation (RRI) studies (Dupret et al., 2022), organisation studies (Farchi et al., 2023), science studies (Aicardi and Mahfoud, 2022), social entrepreneurship and innovation studies (Kosmynin, 2022), participatory design (e.g., Bratteteig and Wagner, 2016), etc., key aspects of cross-sectoral research remain underexplored. Much of the literature on this topic focuses on how important it is to ensure that the perspectives and worldviews of stakeholders are considered when creating social innovation, interventions and design 'leaving no one behind' (e.g., Dupret, 2023). The focus on cross-sectoral scientific collaboration is key to complying with ambitions of responsible research, where focus areas are stakeholder engagement, gender equality, ethics, open access, governance and science education (Dupret et al., 2022: 13). However, less attention is paid to the interpersonal dynamics of collaboration and the emotional labour among collaborators, with some few exceptions (cf. Branch and Duché, 2022; Hillersdal et al., 2020; Resch et al., 2021; Smolka et al., 2021). Hence 'the dark side' was chosen as part of the title of this article, as an attempt to communicate our focus on the interpersonal dynamics within collaborations that are kept hidden and not often directly verbalised and dealt with. Darkness is in this sense a matter of bringing attention to the unknown, such as to the dark side of the moon, proverbially speaking. However, 'darkness' can also sound sinister when social dynamics that are not addressed with care can result in increased inequality, exclusion or marginalisation. The importance of bringing increased awareness to the emotional labour and positioning in cross-sectoral collaboration is hence dual and could work to strengthen scientific knowledge and to decrease consequences of collaborations.

In this article, we examine collaborations that are oriented towards social innovation and societal engagement (cf. Dupret et al., 2022). By collaboration we mean the collective pooling of resources – participants' time, ideas, motivation and/or networks – towards a common goal, done in an inclusive manner, within the timeframe of the project at hand. Emotions play a particular role in collaborations and can be considered a resource. Emerald and Carpenter (2015) describe emotions as assets that can focus or amplify important elements of an interaction. This focus is helpful to societally engaged researchers tasked with promoting reflexivity, because it can guide them towards themes that situate science in society (e.g., values) (Branch and Duché, 2022). Consideration of the excitement, awkwardness or bewilderment of traveling in new collaborative territories may stimulate a sensitivity to meaningful differences (Haraway, 2016). This sensitivity may be prompted by scholarly disagreements that are made legitimate by the conventions of intellectual arguments, but these tensions may also surface in less verbalised ways (Hillersdal et al., 2020). We argue that, especially in newly established collaborations, difference is often first felt or experienced as an affective tension in particular situations, as excitement, bewilderment, doubt, resignation, etc., rather than as an explicated, verbalised understanding. Following Hillersdal et al. (2020), this emotional sensitivity to disciplinary and other types of differences may lead to other ways of addressing a research object and ultimately a societal problem.

In addition to the limited focus on the relational and emotional aspects of cross-sectoral collaborative work in science, we found that while there are increasing expectations on behalf of policy makers, funders and institutions that research be collaborative (Hillersdal et al., 2020), there are no practice-oriented guidelines on how to collaborate. Methodological and analytical guidelines on how to explore and analyse the collaboration are also scant. As we show in the methods section, there were likewise limitations in terms of how we could analyse a collaboration. The paper thus contributes to ongoing discussions within science and organisation studies inspired by the strand of research that has explored emotions in collaborations in the practice of science (Hillersdal et al., 2020; Branch and Duché, 2022; Smolka et al., 2021). We therefore pose the following research question: What role does emotional labour play in cross-sectoral/transdisciplinary research collaborations and how are positions negotiated in this process?

Case study methodology

The overall aim of this article overlaps with the approach of the research endeavour, being a research collaboration that studies collaboration and societal engagement on behalf of researchers. This was a generative overlap, and we present our approach as well as describe the data gathered. Following Brannelly and Barnes (2022) our approach is aligned with emergent methodological developments from the perspective of applying feminist care ethics to research practice. Feminist care ethics seeks to centre care for individual and collective wellbeing and to identify the mutuality of responsibility to remedy social injustice. Such an approach to research acknowledges the challenges from participatory modalities of research and embraces the destabilisation of hierarchies of knowledge and methods for generating them.

The research was conducted by three researchers from Roskilde University (henceforth, the Roskilde University team) with research expertise in anthropology, social psychology and social innovation. The researchers are at different levels of seniority. The Roskilde University team collaborated in collecting and analysing the data. The research subjects, consisting of university researchers and external actors, collaborated among themselves.

The research was conducted as part of a work package of a Horizon 2020 project, in the form of a university alliance.[1] The aim of the study at hand was an increased understanding of the experiences of cross-sectoral research collaborations oriented towards societal engagement and social innovation. The focus of the research is emotional labour in a collaborative environment – such as that of cross-sectoral academic collaborations, a theme that resonates with what Smolka et al. (2021: 1079) call the "affective turn in STS". The specific characteristics of these collaborations include potential differences in tenure and funding among collaborators, what is considered valid scientific knowledge and how this knowledge should be produced, and what the objectives of socially engaged research are. Open calls were sent out to members of the alliance that would enable researchers from universities to conduct minor case projects with participants from at least two universities and societal actors. Three cases were awarded funding of 10,000 euros each. The Roskilde University team's focus was not on the content of the project per se but on the considerations candidates had about collaborating. The cases ran from the autumn of 2022 to the early summer of 2023.[2] The research team followed the entire period of collaborative development of the cases. In terms of the commonalities and specificity of the cases, they represent differences in tenure, disciplines, institutions and sectors (academia, private sector and NGOs). The cases were an amalgamation of political and educational sciences, economy, social innovation, social psychology, management, engineering, information design, coding and the digital humanities. While our analysis is based on a limited sample, we propose that it is illustrative of social psychological mechanisms that are prevalent as structural conditions of collaborations (cf. Dupret et al., 2023) enabling us to extrapolate collaboration processes to the field of democratisation of scientific knowledge and societal engagement in general.

Two teams were composed of only female researchers and practitioners, while one team was a mix of genders. Two teams were composed mainly of social sciences disciplines, while one team represented a mix of STEM and social sciences. Although important observations can be made about how different gendered, discipline- and seniority-related characteristics affected the dynamics of the collaborations, in the scope of this paper we will omit deeper elaborations, due to the sensitive nature of these observations that can compromise the anonymity of the participants.

Participants and observers – who is who – at what stage?

The cases were variously organised, with the non-academic partners being either part of project management or not. In one, they were directly involved in defining and developing the research project. In another, two in the project group played a double role, one being both a researcher and engaged as a member of the non-academic organisation prior to the project, and the other being both a representative of research in the case and a researcher at Roskilde University. In the third case, non-academic partners were involved at a later stage of the project. Two of the cases were all-female teams and the third was predominantly male.

The case participants were relative strangers to each other, with a few of them having previous acquaintance, which perhaps made meetings seem 'public' and less of a space for disclosure and vulnerability. There are likewise multiple roles and directions of exchanges with the researching team that need to be considered. While we took part in many of the meetings between collaborators, the degree to which we were invited to engage with the topics and process of the cases varied. Sometimes we were observing more than participating, at other times the reverse. While during some meetings we were asked to remain silent (although questions were not discouraged), at others the case participants would actively ask for our research expertise and perspectives on issues such as logistics of workshop planning, research design, participatory perspectives, etc. Our reflections on our positioning can perhaps be summarised as follows. 1) We were relegated to the role of the silent partner or funder with expectations of deliverables. 2) As 'the resource', we had an opportunity to network and co-produce with academic peers. 3) Blending of the roles between 'the observer who is a participant' and 'the participant who is an observer'. The latter role is not unique and speaks to the multiplicity of roles and allegiances that many of us have in collaborative projects. Nevertheless, there is a need to find emotional and pragmatic grounds for negotiation and compromise on further action. In the analysis, we address how to collaborate while acknowledging the multiple allegiances that can be at play.

Thus, it was not simply a question of 'investigating researchers' versus 'case participants', but positions changed. We propose that positioning, whether referring to case participants or to ourselves as researchers, is not stable.

Observing emotional labour

Observing the emotional labour in the collaborations, we intended to capture both verbal and non-verbal signals. The verbal included how the participants approached discussing different themes, and how they navigated the misunderstandings, tensions and confrontations that arose. Besides observing the content of conversations between collaborators, we intended to capture the non-verbal clues – changes in the perceived environment of the collaborators' online or physical spaces of interaction. Kolehmainen (2019: 46) refers to such observations as research on affective atmospheres, where the researchers "sense, experience and read atmospheres on-site". To observe and record the dynamic affective atmospheres we integrated our own researcher-bodies as sensors of the research-sites (Dupret and Krøjer, 2023; Kolehmainen, 2019; Smolka et al., 2021). We collected the 'embodied-affective data' (Kolehmainen, 2019: 47) by observing and sensing the changes in the participants tones of voice; changes in conversation dynamics (e.g., interrupting each other, dismissing certain questions and remarks, or bringing up questions that did not mirror the content of the conversation at hand); as well as intermittent changes in the pace and structure of the meetings.

Insecurities on what collaboration is all about

Experiencing the cases as participant observers within a short period of time made the positioning of the different collaborating parties visible. This contrast enabled us to view the differences in both how we position ourselves and how we are positioned in the cases that are given the same conditions for running their respective projects. During our participant observation meetings there were frequent expressions of insecurity and doubt. These expressions were directed towards all participants – collaborators and participant observers alike. Roles and intentions were questioned and the lack of collaborative guidelines and collaborative criteria was called out as an issue (this point is further addressed in the findings). We, the authors of this article, also experienced insecurity with regard to our approach and role. Insecurities about our relationship with those we are researching is a topic of methodological development when applying feminist care ethics to research practice (cf. Brannely and Barnes, 2022). As qualitative research requires relational labour to varying degrees, if professional training has focused solely on the techniques of a methodology we are employing (ignoring the qualities and nuances of developing relationships), one can easily interpret insecurity as failure (Brannely and Barnes, 2022). We chose not to shy away from this insecurity but, following Hillersdal et al. (2020), to treat it as a generative friction that might lead us to reconceptualise the research and help us think of societal problems from more diverse perspectives. Thus, we align ourselves as contributors to methodological debates on feminist care ethics in research practice, as we acknowledge our doubts and insecurities; these are not compartmentalised in the 'darkness' of the unverbalised. We wish, as Haraway (2016) would have it, to 'stay with the trouble' and analyse how different positions and access to resources within research collaboration demand different types of relations, with emotional labour flowing in between.

Description of the qualitative data

The data was obtained through participant observation in online and on-site case meetings and workshops, as well as follow-up interviews with case participants. The online meetings were held on Zoom and lasted 60–120 minutes. Notes were taken during all meetings. Most online meetings were recorded. We attended 16 online meetings throughout the project phases of all three cases and 8 on-site or online workshops or seminars. Online meetings were usually planning meetings, mostly dealing with logistics, and on-site meetings were part of the methodology (data gathering with stakeholders) or outputs. We visited all the cases in the countries where they were based – Denmark, France, and Greece – and followed their collaborations throughout the period of the collaborative projects. Participation at our end in online and on-site meetings and interviews varied between one to all three members of the team, depending on availability. As it was a collaboration on behalf of our team, this implied collective attendance at the events; we all read each other's notes taken during meetings and arranged meetings where we discussed analytical themes, as well as co-authoring this article.

We conducted five follow-up semi-structured interviews with case participants. The interviews were partially transcribed, to highlight sections of interest. The follow-up interviews were conducted after the completion of the active phase of the collaborative experiments. The interview objective was twofold. Firstly, we intended to clarify points that were not explicitly discussed during the meetings we observed; for example, participants' motivation for taking part in this project, how they heard about it, how well they knew the other partners prior to engaging in the collaboration. Secondly, the interviews aimed to give participants space to reflect on their experiences in this project with questions about the collaboration process; for example, how team roles were decided upon, what their obstacles and learnings were, what their experiences were regarding the cross-disciplinary or cross-sectoral nature of the experiments, and how our presence as observers affected their collaborative process. The data collected from participatory observations and the interview data complemented each other. While the data gathered during participant observation allowed us to observe the tensions, negotiations and emotional labour of the collaboration process, the interviews allowed participants to look back on the collaborative experiments and reflect on their experiences: what they learned, what they appreciated and what they would have done differently.

The short time span of the study can, in some respects, be regarded as a methodological limitation. However, it was also an advantage. As all partners were new to each other, that made the establishment of new routines and negotiations visible. Due to the short-term nature of the cases, we had the chance to observe multiple stages of collaboration including the start, consolidation and completion.

Theoretical resources and analytical strategy

Theoretically we draw on concepts from social psychology that help us understand how interrelational dimensions in collaborations can be conceptualised. For us to qualify research collaborations that are oriented towards social innovation, we find two theoretical concepts relevant: emotional labour and positioning.

Emotional labour

We explicitly paid attention to the origins of our own unease, excitement, awkwardness, bewilderment, etc. and acknowledged these emotions as important aspects of the data. Realising that we felt uneasy about certain aspects increased our ambition to explore the meaning and importance of emotional labour, because it pitted us against dilemmas that we had ourselves naturalised and simplified in our professional practice. Due to the complexity of these relational dynamics and their obvious importance to both the process and the output of a collaboration, we have contributed to existing research by discussing whether one should explicitly engage in emotional labour as a professional way to conduct research collaboration.

In the exploration of emotional labour, we draw on a particular part of STS research that studies the role of emotion in scientific knowledge production and cross-collaboration (Branch and Duché, 2022; Hillersdal et al., 2020; Pickersgill, 2012; Smolka et al., 2021). Affective tensions arise in collaborative situations involving different knowledge production practices. This can transform scientists' relationship with their work. Matters of concern can activate and channel emotions, and they sometimes transform the relationships scientists have with their work and its organisation. Thus, science is intrinsically social, with relationships between scientists tightly interwoven with processes of knowledge production (Pickersgill, 2012). Emotions give meaning to the bonds and exchanges in the social groups we belong to and the solidarity we feel with others in those groups (Creed et al., 2014). Emotional displays occur within the interpersonal context of the relationships between researchers, participants, topic and place (Cylwik, 2001). For example, Branch and Duché (2022) show that vulnerability felt by researchers is at times necessary to be able to guide emotional reflexivity and should be taken into consideration when defining and managing emotional labour. While they focus on how emotional labour is about masking the emotional difficulties researchers experience in collaborations, we see vulnerability in collaborations as a dynamic that can contain both potentials and pitfalls in strengthening collaborative outputs. To develop our analytical take we take inspiration from the term 'disconcertment' understood as – "a bodily felt disruption that is experienced when our taken-for-granted assumptions are contradicted" coined by Smolka et al. (2021: 1078). We link it to emotional labour in the sense that we analyse the social dynamics as a professionalised willingness to show emotional reactions of unease or of experienced differences in the partnership and collaborations. While disconcertment potentially risks jeopardising the development of the partnership, it can also show a willingness to be vulnerable. Further, inspired by the use of the concept by Law and Lin (2010) (originally coined by Verran (1999)), we argue that our cultivation and articulation of disconcertment is a crucial tool for interrogating and making visible the political and cultural norms framing our collaborative practices. This approach goes beyond subjectivities and institutional forms, which can have a tendency to reproduce Western knowledge traditions and understandings of hierarchy and authority.

We understand emotional labour as embedded in a political and structural perspective, and we acknowledge that social science methodologies and approaches should be invited to greater openness towards reflexivity. However, what this openness and new types of social psychological dynamics involve in relation to scientific knowledge production is only scarcely researched. An important exception is Hillersdal et al. (2020), who argue that scientific knowledge production is bound to hegemonic (Western) ways of understanding the world. This can potentially be countered by an affective approach to knowledge production that can challenge that view and show how connections between disciplines, people and problems add to an interdisciplinary project's potential for social change. This is an important inspiration for us, as the potential of interdisciplinary research, which has been celebrated as a robust solution to the increased complexity of societal and planetary problems, perhaps lies in the deliberate exploration of contested ground, where the affective sensitivity we experience is important in identifying and defining what action could be taken. When researchers engage in interdisciplinary collaboration with attention to affective dynamics, the potential for a more reflexive mode of knowledge production can be strengthened.

Emotion and affect are used interchangeably in this paper. We approach these as not belonging to particular individuals or representing private emotions. Rather, they are effects of situated practices (Dupret and Pultz, 2021; Hillersdal et al., 2020; Smolka et al., 2021). We approach the affective tensions of collaborative situations as effects of the expectations, institutional conditions and cultures that people have embodied and bring into the situations. Hence, emotions are the effects of the collaborative situated practices, and private and professional boundaries are blurred. Emotional labour has different connotations and theoretical roots both in critical work psychology and more mainstream organisation studies. Some scholars differentiate emotion work from affective/emotional labour by distinguishing between paid and unpaid work (Hökkä et al., 2020). In this paper, however, we use 'emotional labour' to refer both to the paid work needed to establish, say, relations with external partners and collaborators and to the unpaid work part of everyday life necessary to maintain a sense of professional integrity and wellbeing. The boundaries between paid and unpaid work are blurred. These perspectives support the relevance of examining how particular ways of organising – collaboration being one of them – interplay with emotional labour. We build on these research perspectives that acknowledge that there is a lack of both attention to the cost of this work and instruction on how to manage it (Branch and Duché, 2022; Hillersdal et al., 2020). We thus add to the current discussions about the affective turn in science studies by further exploring affect in collaborative knowledge production as generative of new avenues for inquiry.

Positioning

Positioning is a concept that describes how people relate to each other. It is both a process and a dynamic collection of beliefs that results in the individual's understanding of their rights, duties and room for manoeuvre, for example in a collaboration. It is a dynamic process through which roles are negotiated. They are assigned, denied, challenged, circumvented, and redefined either by oneself or by others in the interaction. The roles and the way we talk about them and act within them determine the boundaries of the collaboration and the meanings of what people say and do. Branch and Duché (2022) suggest that researchers' positionality is also relevant in how they adapt research tasks within a sociopolitical context, and they challenge the idea that researcher objectivity should exclude affective dimensions. Moreover, they point to the fact that when looking at positioning in collaborative research, the focus has often been on how participants would be marginalised or excluded, while less attention is paid to the dynamics of how researchers become affected and are vulnerable in these types of collaborations (Branch and Duché, 2022).

During our observations, we took note not only of what was said, but also of the many instances of silence, interruptions, confusion, questions that were left unanswered or issues that were brushed aside. These perspectives aid us in our thinking about the consequences of what is not made explicit in collaborations. As we show in the analysis, one needs time for positioning, for discussing, for making things visible. An emotional labour approach aims to make things explicit in exchanges where they are implicit.

Through investigating different dynamics of positioning, we get an understanding of the social, individual and moral factors at stake in collaborations. Theoretically, we draw on the initial work on positioning theory by Davies and Harré (1990). We will address positioning according to the specifics of the situation and who is involved in the positioning (self, other). Given the dynamics of the interactions, we argue that positioning is always interactive. We view positioning in collaborative projects as being tied to legitimacy, implying the right to occupy a particular position of power. We thus examine what behaviour and strategies our informants applied to position themselves and to relate to others.

Analytical strategy

We chose to follow the abductive approach as our key analytical strategy – going back and forth between the data and the theory, shifting between consolidating conceptual and empirical themes (Timmermans and Tavory, 2022). After each meeting where we, the authors, engaged in participatory observations, each author wrote notes with their initial reflections and emerging analytical themes. These notes were exchanged by email after each meeting. When the observations and follow-up interviews were completed, meeting recordings and interviews were partially transcribed. The authors started thoroughly reading the compiled data (transcripts, meeting minutes, notes after meetings, interview transcripts), making notes of emerging themes and concepts. Following the abductive approach, we allowed the data to drive the emergence of initial conceptual themes; for example, noting the diverse facets of emotional labour which emerge at different stages of collaboration – starting, consolidating and concluding. Later we went back to the empirical data to retrieve examples of participants' quotes or descriptions of situations from the interactions between participants, which would illustrate the conceptual arguments.

Analysis

In the analysis section, we view collaboration as a process that runs through three stages: starting, consolidation and completion. These stages link to other experiences as well, including both private circumstances and those present in collaborators' working conditions or organisations. Emotional labour is shaped by living conditions and the number of caring responsibilities in general, people's engagement elsewhere, whether they need to be away from home and have work-related caring responsibilities or are emotionally involved with the study cases in their research.

Initiating collaboration – working with strangers

This analytical section deals with emotional labour dynamics that are particularly prevalent at the beginning of a research collaboration. The dynamics and exchanges are focused on the logistics of project execution and getting to know each other, less on differences in scientific approaches and methodologies or research questions to be developed.

We noted that collaborators might, from the outset, try to smoothen any differences in joint interests and mission. As observers of three case studies, we took note of there being an openness during these initial meetings, expressed as time spent on activities such as "checking the energy in the room", or conversing in a way that can be interpreted as chatting and being playful with the amount and type of methodological and/or theoretical approaches that could be applied further on in the project. Participants kept potentially different or conflicting interests mostly to themselves. We can speculate that focusing on the logistics related to deliverables was a comfortable way to create a seemingly effortless and disagreement-free environment. This phase, in which positioning dynamics are not explicit, was characterised by an unspoken agreement to keep questioning and sharing of concerns or vulnerabilities to a minimum. Aspects of this largely hidden emotional labour, such as trying to fit into the flow and concealing one's doubts and questions, only become visible retrospectively, in later stages. Not all decisions to "go with the flow" are necessarily experienced as positive. Collaboration can also imply, or demand, a self- and mutual erasure of differences between partners (Breeze and Taylor, 2018: 24).

When the informants later reflected on things they could have done differently, that also indexes this difference of opinion or approach that they might have held during the meetings with the teams. This calls us to consider what emotional reactions collaborators (including researchers) might be erasing in themselves or hiding in collaborations. As we will show below, a more visible positioning dynamic appears in collaborative breakdowns (such as misunderstandings, or questioning). For example, during one follow-up interview, a researcher shared that, because not all the research partners were engaged in collaborative proposal writing (they were invited to the project at a later stage), this researcher was under the impression that the project was of a different nature:

> But that was my mistake, I was not engaged in the project from the very beginning. (…) I thought it was about working with students, or to visit other countries with students, other university systems,

> or having joint courses. But then I saw it was a research project. (Researcher 1)

This researcher spoke about the assumption that the nature of the project was clear to everyone involved, although this was not the case:

> And I thought it was clear for everybody. And maybe if I knew it was about a research project, I would apply myself differently, I don't know. (Researcher 1)

The researcher shared that although there was no unified consensus from the beginning on what the project was about, the initial meetings were not dedicated to clarifying these differences and creating a unified vision between collaborators. The researcher expressed regret that these different visions about the output and goal of the collaboration were not discussed from the beginning, and that participants dived into activity planning without clarifying the various roles and addressing uncertainties:

> The meetings were just to organise the … [deliverable], but the objective was not to create a common culture between the backgrounds. (…) We didn't talk about our perceptions, about our role in the project. We started the project directly and the objective was to do the … [deliverable]. From the first meeting it was as if I had the same points of view as others. ... But this common thread, it wasn't really set. (Researcher 1)

In the end, participants shared their appreciation for being involved in the project because it gave them the opportunity to delve into topics and methodologies they were not familiar with. They said they were happy to "go with the flow" because of the new insights gained. Because researcher 1 was not engaged in writing the proposal and defining the objectives from the beginning, they might have felt uncomfortable about sharing the feeling of misinterpretation of the nature of the project, and hence made the choice to get on board along with the other partners, without explicitly calling for renegotiation of the project's objectives: "From the meetings, at different moments, I started to understand" (Researcher 1)

In such instances, the individual requiring visibility for their concern could end up being blamed for the breakdown, rather than addressing what the collaborative process – as we know it – has required: for some subjects or topics to be neglected, silenced, or hidden. Aiming for collaborations to be or seem smooth could perhaps indicate an overruling of certain positions by others.

Summing up on the initial stage of collaboration

While there might be anxiety and vulnerability in the initial stages of collaboration, particularly when it implies working with strangers, it did not seem to be addressed during our observations. This may be for a good reason, as professional emotional labour also implies 'putting on a face', which usually means inhabiting the culture and discipline oneself to adopt a role, or sometimes, even a mood. It is a way of making oneself appear welcoming to others. We suggest that in cross-sectoral collaboration, experienced partners know how to strategically be diplomatic at the beginning, to get the collaboration established. However, there may also be cultural differences at stake in how 'putting on a face' is interpreted and practised; some may be particularly welcoming, others may be more reserved in relation to new collaborators.

In all three cases, collaborations were initially oriented toward logistics about when and how to meet with each other and with external stakeholders. Doubts that might have changed the direction of the project were possibly kept at bay, and perhaps decision-making was not equally distributed. When external stakeholders or even partners are involved in negotiation, who has a right to define things is not visible. But explicit positioning is not a win-win approach per se, as a nonconsensual demand of mutual affective sharing can also be exploitative. At the outset, people are new in the positioning dynamics of a collaboration and might not know the agendas, power and interests of others. If one is in a precarious position or pressured situation (on a personal, professional and/or organisational level), it can perhaps seem logical to be cautious about making visible one's preferences or information, and even more so one's insecurities and feelings of vulnerability.

Consolidation

Once partners have had their tasks and various resources clarified, mandates and decision-making power are negotiated. More explicit conflicts seem to follow the initial phase, where the realities of concrete tasks, resources and responsibilities must be addressed (Pultz and Dupret, 2023). At this stage, we experienced explicit positioning dynamics related to issues such as authority and legitimacy, with disconcertment coming clearly into view. This section deals with these aspects of emotional labour.

Acknowledging disconcertment as important in emotional labour

As time elapses, concrete decisions and distribution of tasks and responsibilities are negotiated. In the cases included in our research, the initial excitement seemed to change character, as agendas became even more pragmatic and movement from one item to the other accelerated, bearing in mind the short duration of the project. Disconcertment increased, as did the attempts among collaborators to smoothen things out, trying to present the collaboration as a harmonious experience among participants where all collaborators are on the same page. Feelings of disconcertment growing from disrupted certainty are a very common but rarely addressed aspect of interdisciplinary collaborations (Smolka et al., 2021). Disconcertment arises from collaborators "detecting metaphysical or epistemological difference" (Smolka et al., 2021: 1081) between their disciplines and worldviews. In that paper, the authors describe disconcertment as an emotion that is embodied – for example, expressed in uncomfortable laughter. Addressing collaborators' disconcertment requires feeling safe to express it and others to detect it. To create a collaborative atmosphere where disconcertment can be explored, "collaborators must perform the work of attention, sensitivity, and cultivation—in other words, they must perform affective labor" (Smolka et al., 2021: 1083). Our observations of collaborative experiences suggest that engaging in emotional labour and exploring each other's disconcertment could help avoid rendering invisible some collaborators' questions and uncertainties.

For example, in one project, disagreement and different expectations started to resurface explicitly during one of the final Zoom meetings, when participants delved deeper into the data collection method. The dialogue in this meeting revealed to us observers and to the participants some of their crucial differences in understanding 1) what is valid (scientific) data, 2) what the objectives of data collection in the project were, 3) what the objectives and scope of the project deliverable were, and 4) what resources were available for data collection.

> Is it scientifically valid if we have the written input from the participants and we add some notes, (…) it will be on a very subjective level, does it make sense? (External partner 1)
> Is there a scientific objective here? Our objective is to disseminate. (Researcher 1)

> I do not have the capacity to transcribe, and I cannot hire someone to do that. It is not viable for me. It's a no. I mean, I can, but it would be abusive. (…). This is a small project, I cannot do. (External partner 1)

For us as observers, the disconcertment that was felt during the meeting was a productive source of reflexivity – it felt like an opportunity for participants to visibilise and discuss the assumptions and beliefs about what being objective or subjective means for (scientific) knowledge production, and if or how research can combine multiple objectives, for example, data generation and societal engagement. Participants interpreted the disagreements revealed as a signal to step back and discuss different expectations of the project outcomes:

> From what I hear, we might need to sit ourselves down and to stake out what is the scope of what it is that we want to do in terms of publication. It sounds to me like we are coming from different expectations, from different objectives. (Researcher 2)

With our case observations, we have also experienced disconcertment and boundary settings on the part of case teams toward the Roskilde

University team of researchers. This happened sometimes when we inquired directly about how collaboration was experienced by the case team. During our initial observations, we noted that there was excitement about the Roskilde University team's presence during the meetings. Over time, on several occasions we were called to re-establish our transparency in our role as observers. We reminded case participants of our motivation in coming to the meetings. Participants in one case, for example, expressed that they would like to have the meeting on their own to establish their roles and achieve a mutual understanding of core concepts, or as one informant put it, "…we need time as we do not share the same discourse." They suggested that this initial mutual sharing was only possible without observers. Boundary setting and positioning of others as not belonging among the collaborators can be an ambivalent process, because while for some, communicating a clear boundary can be perceived as a necessary element of defining a transparent work process and a delimitation of decision mandates, others can perceive it as control. How boundaries are communicated and perceived also depends on the norms under which collaborators were professionally socialised – depending on a sector, academic culture, performance criteria, etc. Hence, finding space for reflexivity about how we set boundary positionings and how we perceive each other's boundaries, especially in collaborations with actors from different backgrounds, is important for inclusive collaboration processes.

What kind of power relations must collaborators comply with when addressing disconcertment in front of the other collaborators? Emotional labour is not only about registering emotions but also about expressing and feeling emotions that are considered 'suitable' in a given setting/organisation (Dupret and Pultz, 2021). The 'suitability' is quite central, because it is discursively defined and reinforced through power relations and norms. Engaging in emotional labour in ways that make more explicit what collaborators express emotionally can help us understand the differences in what types of knowledge are approved of and reinforced through power relations and norms.

Dynamics of legitimisation

The dynamics of (de-)legitimisation often become visible in the consolidation stage of the collaboration, especially when disagreements are more visible than in the initial phase. Professional (de-) legitimisation and positioning processes emerge to navigate negotiations which are inevitably interwoven with power relations.

> You call it collaboration; we call it engagement and responsible research (External partner 1).
> I have read Vygotsky about the importance of understanding context (External partner 1).
> Without structure, we are just talking (Researcher 2).

During the observations, we witnessed these positioning dynamics in the form of, for example: showing an awareness of the requirements of funding bodies (as we were understood to be by one participant, who asked to discuss how to generate a deliverable from the data collected); positioning oneself as an experienced professional (participants mentioning how their various research responsibilities and managerial roles provided them with insights on project and team dynamics); positioning oneself as academically knowledgeable/excellent by bringing up a recognised academic name: "This is a great paper. It has been written by …(name), who is one of the top figures in [this discipline]" (Researcher 2); questioning the authority of an academic partner by suggesting that the person's use of certain qualitative methods was not 'hard data', hence not scientific and therefore delegitimising the validity of the collaborative process, but also inviting another researcher with expertise in the same qualitative method to evaluate the use of this method. The twofold delegitimisation/legitimisation positioning of oneself and others seemed to be a quest for authority to define the right to evaluate and decide the method used.

These positioning processes are performed through: calls for structuring (professionalising) the collaboration, appealing to standard ethical concepts such as 'transparency', summoning authority based on professional visibility or by being theoretically savvy. In these positionings, going with the flow, spontaneity and improvisation are seemingly made invisible. They can reinforce traditional academic and non-academic hierarchies, making it difficult for collaborators to experience new roles and tasks in these projects. It can also make it harder for partners that are in some way a minority in the collaboration – by, say, being the sole representative for a discipline – to impact the direction. Collaborations, as we show in the following section, need to maintain their openness to questioning, as it keeps open the possibility of exploring and including different voices. The balance between saying and agreeing with something that creates a good atmosphere, on one hand, and questioning positions, project aims, differences in epistemologies, etc. on the other, is a central part of what a collaboration is.

Engaging with concerns

In our social interactions we always talk against a background and within a context. We are always contrasting our experiences and making meaning from what we think or feel. Collaborations are particular because they can be so intensely relational, stirring and catalysing these processes of meaning-making. In collaborations, there needs to be a consensuality of design. The definition of problem and methodology should leave ample space for participants to ask questions and make amendments both at the outset of the project and along the way. There needs to be time for discussing and engaging with differences and decisions. When we collaborate, do we talk about who has the right to define the direction the project is taking?

On several occasions, we witnessed participants being marginalised when their concerns were made invisible by a change of topic or brief answers that did not align with the questions raised. During one instance, for example, a case participant suggested to their team members that they address a particular concern. Several times during the discussion the participant's concern was overruled by prioritising space to address the logistics of meetings and planning, and saying that the concern could be addressed afterwards, which could be seen as trying to make the collaboration seem harmonious.

> Researcher 2: Are you kind of on board with the things that we have said and where we are converging on?
> Researcher 1: Yes, there is no problem for me, I just need to know the problem of this [deliverable]…, the objectives, the scope.
> Researcher 2: Why don't we make this the guiding question for the next meeting, so after we've discussed all the workshop practicalities, we talk about the tension or the spectrum of….
> Researcher 1 (interrupts): Because I think all of us need to define the objective and the problem of this [deliverable].

Postponing to address concerns can be seen as delegitimising the needs and concerns of the person who was not aligned with the direction the project was seemingly taking. This participant was questioning, rather than giving solutions and suggestions. This role was positioned as marginal in this situation. The team was going for the thing that works, the smoothest solution. Thus, we experienced how, when a member of the group was questioning the central premises of their collaboration, this mutual questioning became a source of tension rather than a source of co-production.

The emotional labour that brings collaborative concerns to the table involves being clear (both to oneself and to collaborators) about what each one of us wishes to make visible. The positioning dynamics we experience may in turn raise reflections about whether to make visible the specificity of our institutional/sectoral behaviour, culture or power. Naming something in a collaboration can function as an erasure of these differences. Based on our observations, collaborations can easily slip into self- and mutual erasure. What is implicit is only made visible in collaborative breakdowns, exemplified by misunderstandings or questions. The person questioning can be blamed for the breakdown, rather than examining what collaboration as we know it has required: that some subjects or some aspects of subjectivity be neglected, paused, made invisible. Does collaboration then imply a particular kind of compromise that depends on emotional labour and positioning dynamics? This can mean compliance to the tune of whoever is the loudest, has the most power, or claims a particularly vulnerable position that the collaborators are positioning themselves within and committing themselves to in the name of 'care ethics'.

Summing up on the consolidation stage

The consolidation phase of collaborating is when concerns are more clearly negotiated. During this stage, differences in collaborators' objectives and academic worldviews produced feelings of disconcertment and "the unsettling experience of questioning what had so far been taken for granted" (Smolka et al., 2021: 1090) – feelings which can be unwelcome by other collaborators because they seemingly disrupt the harmonious flow of collaboration. However, following Smolka et al. (2021), if addressed with a level of reflexivity, disconcertment can produce awareness among collaborators regarding their "ingrained ... scientist habitus" and "perceptions of normality" (Smolka et al., 2021: 1091). It is an awareness that can be an asset in producing responsible research and societal engagement with external partners. In the observed cases, disagreements and disconcertment might have been more disruptive than generative at the time, but they were approached as reflexive learnings afterward.

The question then arises: how can the discomfort and unsettlement when facing differences, often accompanied by dynamics of invisibilising (of topics or people), which almost inevitably arise in heterogenous and new collaborations, be sources of reflexivity (about our positioning as knowledge producers and relational human-beings)? Power can be treated as an absent-but-implicit, which is made present in 'collaborative breakdown'. Consensus and attempts to smoothen things over do not signify the achievement of harmony and alignment of the team members but perhaps an overruling of a certain position over others. Apparent consensus is not an absence of difference but perhaps the acceptance of demands for positioning each other and oneself as invisible.

Completion

This final analytical section deals with how projects were completed in each case and the interpersonal positioning dynamics during that stage. During one meeting to which a case team had invited external participants, the focus was to interact with these participants and consider possible future collaborations. However, one of the team members kept steering the plenary discussion toward finding specific proposals and solutions for what the final output of the collaboration should be. This team member on multiple occasions positioned us as representatives of the Roskilde University team, seemingly seeking guidance on what the format of the meeting might be and its potential takeaways. Several other members of the case team seemed confused by this focus and attempted to shift back to the content of the event at hand. The attempt to attach a particular mandate of deciding collaborative takeaways and formats for our participation in the event can be seen as an effect of internalising the external expectations in defining the success of a project or a collaboration as based on the timely production of deliverables. Also, it held us in a rather stereotypical position of 'funder' with concrete expectations of material deliverables by certain dates. Societally engaged research projects can often play into these types of instrumental requirements. This team member's reactions turned out to resonate not only with the type of deliverables often expected in collaborative research projects but also with the hectic pace of daily work-life that this case team member possibly experiences. The consequence is reduced space for open-ended exploration. The Roskilde University team discussed how this was, in fact, not so different from our professional lives as academics, where we are reliant on external funding for continued research, and we were reminded that while we did not share the case team member's concern for their specific deliverable, we too had worries about our own deliverable. While our analytical gaze was on the quality of relationships, we had to keep an eye on our external expectations. Our conditions mirrored each other.

In another case observation, we yet again noted that the Roskilde University team could be perceived as such a source of external expectations, but, in this case, as an expert resource. During our initial meetings, the senior member from the Roskilde University team questioned how the academic collaborators from the observed case understood their involvement with external actors, because the extent and nature of the case's involvement with these actors was not clear to the Roskilde University team. This resulted in a lengthy discussion between the case team and the Roskilde University team about the meaning of involvement, participation, and collaboration. The senior representative of the Roskilde University team was invited to provide concrete suggestions on possible modes of involvement, as well as to comment on their possible analytical significance. During a later on-site meeting, one of the case participants addressed this question directly, saying that they have been "good" at changing the focus after what they took to be an intervention at the Roskilde University team's end and re-thought participation and motivation in the project. As can be seen, our questioning shifted our positions as observers to participants, but perhaps also showed us as somehow having the power to expect a particular outcome from the case. The positioning of the senior member in the Roskilde University team as an expert can relate to several aims, such as acknowledging the need to qualify participatory dimensions in the collaborative project at hand, simply to make its impact better; to problematise participation within their team and with external stakeholders; to build relationships by acknowledging the role of the Roskilde University team member as a senior, with previous experience of similar research.

Another case observation illustrated that our presence, observations, and questions may have been perceived as an obstacle to case participants reaching their goal. Prompted by questions to reflect on their collaborative experience, a participant said that the focus on collaboration is a meta-perspective that they are not trained to conduct and do not have time to do. Their focus was on the particular project and managing the goals they set out to achieve. In this case, the goal of the project was tied to the specific academic goals of several of the participants. They wanted to dedicate their time to ensuring that the logistics were in place and that more strategic academic outputs, such as articles and academic presentations, would be tended to. In this example, the Roskilde University team was positioned as the ones responsible for the reflexive dimensions of the collaboration, as that was seen as the Roskilde University team's focus, hence not in the strategic interest of the case team. But this was not something that should be part of the cross-sectoral collaboration at hand. The positioning of the Roskilde University team placed us as experts on the topic, who could evaluate how the cases diverge or conform to an ideal type. But this was not what others were skilled at or should be expected to do, particularly not those who might have been trained in disciplines that were dealing with macro-structures and not human micro-interaction per se. Even though emotional labour is mostly researched and applied in sectors involving relation work, such as services and care, collaborative work is in fact part of most sectors today, increasing the importance of raising awareness of how interactions and science production are affected by this additional work, regardless of the scientific paradigm applied or the scientific question being researched. This perspective posits reflecting on and working with how we work in collaboration as a 'nice-to-do' rather than a 'must-do', as yet another item on the invisible labour list. In the consolidation phase, the quality and potential of the relationships might be worked on but still approached as an appendix to the time used on project deliverables. Emotional labour implies that interpersonal exchanges in collaborations do develop and shift but rather out of sight, on the collaborators' own time and initiative.

In follow-up interviews, participants shared their appreciation of the learnings that the collaborations have brought them. Interestingly, most of these learnings were related to the differences (cross-cultural, cross-disciplinary or cross-sectoral) which, during the consolidation phase of the project, had often caused tensions, misinterpretations and disagreements. During these interviews, participants shared their professional learnings and the impact on them in terms of reflexivity.

The exchanges that we had during the follow-up interviews were different (often more reflexive and transparent) than the data we collected from the observations. This was probably because of the temporal aspect, as participants had time to think through their experiences, but perhaps also due to the shift in all our roles in the interviews compared to the observations, from them being observed by us to being a conversation partner and a more active co-creator of data. This resonates with the pressure felt when participating in projects with funding tied to project descriptions and outcome expectations. Much can be at stake, such as livelihood, reputation and ideas about professionalism. However, the disconcertment of feeling observed and possibly 'evaluated' is an important dimension that may merit reflecting upon by all participants in the collaboration. It is an inherent part of interactive positioning. Hence the establishment of trust and transparency is central to be able to balance constructive collaboration with leaving space for questioning.

Summing up on the completion stage

The conditions under which the three observed collaborative research cases unfolded were particular in that observers were present during the interactions. While this role was a source of some anxiety and there was a need for clarity of boundaries and expectations, as we showed, it seems that it was beneficial for participants to have the space and time for reflective discussions on how they collaborated. The appreciation was most prominent during the follow-up interviews, where case participants could voice concerns that they might not have had the opportunity to address during meetings in which the focus was predominantly on logistics.

From our perspective as observers of three cases, it seems to be helpful if cross-sectoral collaborations were to include time for reflecting and voicing concerns that might not be given space in purely logistical meetings. Nonetheless, in one of the cases, where reflecting on the process of collaboration was prompted by our Roskilde University team, we could feel some resistance. It was framed like a strategic concern rather than an element that would benefit teamwork in general. This tallies with a point made previously, that talking about our doubts and concerns demands a level of vulnerability that goes beyond the experience of disconcertment. It should be done consensually, and perhaps with an openness that not all will be willing to share, making them vulnerable. Lacking consensuality on this matter can make it seem like boundary-crossing.

Discussion and concluding remarks

We are asked to collaborate, but it is not made explicit what that entails, and we do not enter collaborations having explicit tools and strategies to do so. Researchers often attend to collaboration as a necessity and requirement on behalf of funding bodies, or as a side-effect, as an invisible but necessary commitment. Collaboration seems to be treated as mundane, relational and gendered knowledge, and thus, rendered invisible, but it nevertheless influences how knowledge and experience are constructed. We have learned from other scholars within the field of collaboration/integrative research who apply an affect and feminist approach in STS, e.g., Hillersdal et al. (2020), Smolka et al. (2021) and Branch and Duché (2022), that affect plays an important role in collaborative dynamics. For example, Hillersdal et al. (2020) point to the fact that, as a consequence of the political drive towards finding societal solutions through cross-sectoral collaborations and the funding criteria that follow from this development, there can be a risk that collaborating research teams are formed based on strategic intentions rather than on collective reflections about how to organise and practice interdisciplinarity. Interdisciplinary and cross-sectoral research collaborations thus tend to figure mostly at a strategic level and in external presentations. Internally – they argue – within projects, the way forward is diffuse. Through an analytical STS approach, they demonstrate how it is important to account for affectivity and sensitivity in order for collaborators to strengthen their ability to act in relation to other people's interests that one does not necessarily share. This sensitivity makes available other ways of sensing and tackling problems that can challenge power structures and hegemonic practices.

We add to Hillersdal et al.'s (2020) approach to the experiences of everyday collaboration by expanding the analytical concepts applied. Through positioning, we keep an awareness of how there are no easily defined strategic or structural answers to collaboration. We show that attention to everyday experiences, this does not mean that interests, roles and power dynamics can be stabilised, and hence foreseen, or managed. Rather, through an affective STS approach we show that the positioning and roles of collaborators are dynamic. The importance of making visible or keeping invisible is situational and should be evaluated in relation to possible reinforcement of power dynamics and other types of vulnerabilities. If collaboration keeps on being treated as mundane, it leaves collaborators in a situation where the premises of collaboration are based on presumptions about the various partners' cultures, interests and resources and, not least, decision mandates that are not explicitly acknowledged. Likewise, how we understand science is still associated with ideas of neutrality, thus leaving no space for addressing emotional labour. This acknowledgement has had very different trajectories in scientific disciplines and institutions, but the amount and nature of interpersonal work required to collaborate is still not widely addressed, with a few exceptions (e.g. Hillersdal et al., 2020; Smolka et al., 2021; Branch and Duché, 2022). In this paper, we have analysed the lack of acknowledgement of the emotional labour involved in research collaborations, as well as how this makes it difficult to address and distribute the tasks and processes required to ensure an inclusive and socially sustainable practice.

What we call professionalisation of collaboration, or addressing it as a standard procedure nevertheless, might have consequences beyond the fact that it is resource-intensive. While the inclusive methodological approach and a degree of intimacy between cross-disciplinary scientists are essential to knowledge production, emotion research practices can, paradoxically, have undesirable implications for the structuring of work and the social relationships underpinning responsible scientific knowledge production. We need to question what it would take for wide dissemination of skill sets and discourses around collaboration, as it can make some actors' collaboration 'unworthy' as they do not have the institutional support and access to collaboration upskilling resources to collaborate in a professionalised way. Furthermore, addressing emotional labour in collaborations is not without its problems. People do not easily share their vulnerabilities and expectations. Expressing vulnerabilities could potentially affirm hegemonic positions, both within the team and also in our exchanges as a research team observing collaborations. People are not necessarily used to such types of collaboration (which might be considered slow, demanding affect, revelation of matters that are private and thus seemingly irrelevant, etc.), which in many academic settings might be considered 'unscientific' and could therefore cause unease. While studies on affective collaborative research within the field of STS – including our own – suggest more attention should be paid to feelings and emotions in our professional work, we also raise the concern that proposing to listen, and be aware of emotions, attending to psychological dynamics requiring intimacy, can be very hegemonic and marginalising. It can require a personal commitment in professional relations, which is something you are not entitled to expect nor should you be coerced into providing simply because you are collaborating. One can raise these issues for discussion and perhaps question who has the right to define how the collaboration should go. Expecting collaborators' inner experiences to be made accessible could also threaten to expose these in another arena of capitalist exploration and exploitation, such as in scientific publications. This tension illustrates the point that sometimes when we collaborate, the result of our collaborations is out of our hands. Both the process and the product can have detrimental effects because they acquire a life of their own and can be used and misused by others.

Based on the insights obtained from the analysis of emotional labour and positioning, how should we then design research collaborations? We can start by acknowledging that collaboration is a highly sensitive matter; it involves participants' sense of self and can trigger insecurities and feelings of incompetence. Collaboration in most fields of research depends on lengthy tacit or embodied experience. One can, perhaps, consider and acknowledge one's own and other collaborators' needs (or lack thereof) for attending to the emotional dimensions of a collaboration, and the boundaries of doing so. We are called to acknowledge our interconnectedness and our mutual vulnerability, to take care of each other and to ask ourselves how we make sure we acknowledge this fundamental premise that we are interconnected. This perhaps demands making space for uncertainty and questioning. Or perhaps accepting that collaboration should not be expected but actively negotiated.

We call for the provision of adequate space and resources in collaborative projects for (in-) visible interpersonal dynamics to be attended to, in ways that make it possible to negotiate power imbalances in a consensual manner. We acknowledge that rendering visible the implicit dynamics of emotional labour and positioning is not necessarily the way to increase the experience and outcome of collaborations. However, it is an important takeaway that the inconsistencies of interpersonal dynamics are difficult to deal with and should not be instrumentalised per se.

This paper further contributes with an empirical dimension to the body of literature addressing emotional labour and positioning. Adding to existing research that includes the role of the researcher, or academic, in the analytical gaze (e.g., Hillersdal et al., 2020), we show how our positionings not only vary across different collaborations (e.g., funders, controllers, experts), but also shift in time (e.g., from initiation of collaboration to its completion). As such, it is an addition to the emerging field that addresses the complexity of relational dynamics and emotional labour in cross-disciplinary and cross-sectoral collaborations.

We have found that relational issues come to light in moments of confusion, questioning or conflict. This approach perpetuates the lack of any process or approach that collaborators could adopt to act otherwise. Nonetheless, this is an aspect of collaborations that could have the potential for mutual learning through the inclusion of silenced perspectives, which could generate different approaches to innovation and problem-solving. If we are to tackle complex societal problems, we need to understand and learn from different partners and perspectives, particularly those that challenge 'established' ways of doing things, as that could challenge power relations. The increased quest for science to be oriented towards societal engagement and social innovation calls for professionalisation of cross-sectoral collaborations. This paper contributes to pinpointing the important focus on emotional labour as part of cross-sectoral collaborations that should be considered in future research, in ways that acknowledge that emotional labour takes place at all levels but may be rendered invisible.

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Notes

1 The three collaborative experiments that this paper is based upon are initiated and have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101035808 work package 3 headed by Roskilde University.

2 One of the cases was eventually withdrawn from the case study due to a high level of vulnerability and concern for the external stakeholders collaborating with the team. Adding an extra layer of investigation could potentially impose too much stress on both the implicated researchers and the external stakeholders and add an increased amount of complexity to the different layers and roles among the various collaborating participants. The case therefore primarily serves as general background knowledge.

How Plastics Came to Pollute the Technical Literature: Evidence from US Patents on Facemasks

Franck Cochoy

Toulouse Jean-Jaurès University, LISST-CNRS, Institut Universitaire de France/cochoy@univ-tlse2.fr

Abstract

Today, we know a great deal about how plastics invade the oceans, but we know less about how these same pollutants begin to colonize the world upstream, even before the manufacturing process, when inventors draft their patents. This paper addresses this gap through a textometric study of the corpus of US facemask patents over a century. Patents are highly constrained by specific laws and rules: they must focus on utility, and only on utility, thus preventing moral concerns such as care for the planet from being part of the patenting process. They must also be generic, which prevents them from focusing on specific materials. Despite these limitations, the empirical analysis of our corpus reveals the linguistic tricks and cultural patterns that have allowed plastics, but also health and environmental concerns, to circulate in patents. The use of certain rhetorical devices, such as "preferably" and "or any other suitable material(s)," helps to mention specific materials while preserving the genericity of patents; in addition, the reference to market-based components contributes to externalize environmental and health considerations. As the analysis shows, most of these patterns contribute to deepening the production of ignorance in contemporary societies, although recent developments offer a glimmer of hope: the reference to external pressures for sustainability, or the transformation of the concept of sustainability into a material property, has helped to transform ethical concerns into useful facts, thus facilitating the replacement of plastics with more sustainable materials in the patent literature.

Keywords: Patents, Plastics, Ignorance, Matters of Concern, Health, Environment

Introduction

The Covid-19 crisis was not only a major disruption in the normal course of human history; it was also, in some respects, a return to the past. After decades of environmental progress, including a growing awareness of the threat posed by the proliferation of plastic materials in the environment, the need to fight the virus and the means to do so led to an impressive comeback of plastic-based solutions. During the pandemic, plastic gloves, shields, packaging of all kinds, and Plexiglas windows proliferated at an unprecedented rate. In a speech published on September 10, 2020, on *Plastic News*, a web journal of the plastics lobby, the CEO of the Plastics Industry Association proclaimed, "Plastic saves lives" (Radoszewski, 2020). Plastic has certainly helped to save lives, but in doing so it has also contributed to the introduction of the following paradox: if plastic saves lives, it also kills the planet and thus endangers the long-term conditions of human existence (de

Sousa, 2021) – in other words, plastic saves some of us and kills everyone at (not exactly) the same time.

In this paper, I would like to address this paradox by examining what is probably its most material and symbolic embodiment: the sanitary mask. This device, now largely made of plastic, was one of the main tools designed to contain the pandemic. The mask is a weapon against toxicity, but this weapon is made with toxic materials: although some chemists claim that plastics are not toxic per se, their construction contains several toxic substances (Liboiron, 2016). Moreover, plastic masks may end up invading and contaminating the land of other entities (air, rivers, oceans…), and as such they are part of pollution as a new form of colonialism (Liboiron, 2021). As such, the mask is what Plato called a *pharmakon*: it is both a remedy and a poison (Derrida, 1972). The mask epitomizes the fate of modern objects: its short-term usefulness obscures its long-term hazardousness, along a technological version of the "whatever it takes" rhetoric. The present usefulness of plastic masks conceals their future danger: on the one hand, polypropylene – the most common plastic component used in masks – is recognized as the safest plastic for the human body (Kumar, 2021), with the best filtering properties compared to other materials (Wang et al., 2023), so that it is likely to be difficult to replace; on the other hand, the same material becomes harmful to wildlife when burned (Purohit and Orzel, 1988) or dispersed in the form of microplastics (Hwang et al., 2019: 684; Jeyavani et al., 2022). In other words, polypropylene masks are subject to a 'Gremlin effect': just as the well-known creatures looked harmless, cute and friendly when used properly, but turned into terrifying monsters when exposed to light, wetted, or fed after midnight, health-protective polypropylene masks become a threat to all living entities, including ourselves, once released and degraded in the environment. This tragic metamorphosis is all the more common because people often perceive these masks not as plastic but as objects made of paper (Cochoy et al., 2022), and thus tend to use them without any sense of guilt and to release them more easily into the environment – during the Covid-19 pandemic, plastic face masks became a new item of waste polluting the oceans (Parker, 2021; Peng et al., 2021).

Therefore, I propose to investigate how plastics have been involved in the scientific and technical development of facemasks since the early 20th century. This study helps us understand why plastics were so easily incorporated into facemasks, and why the associated health and environmental concerns were overlooked in the patent literature. I conduct this research based on this latter corpus. In contrast to myriad studies conducted in law and economics that look at patents from afar, as black-box type of assets used in economic strategies and legal battles (for reviews of the literature, see Pénin, 2017 and Cochoy, 2021), I will join the few STS studies that take the content of patents seriously, as a repository of technology but also social history. Focusing on patents is important, because these documents contribute to shape techno-economic agencements, for instance by introducing new technologies and approaches in market organizations, bringing new consumer habits, and so on (Parthasarathy, 2017). Suggestive and recent examples include Jungnickel's studies of how patents on clothing inventions such as convertible cycling skirts helped women overcome the restrictions imposed on their sex (Jungnickel, 2023a, 2023b). In this vein, my own case will examine the extent to which patents may not only "hold social and technical stories" (Jungnickel, 2023a: 14), but also convey material and moral elements that both fuel and shape the latter.

The research is grounded in the perspectives of science and technology studies and scientometrics, based on a tradition initiated by Michel Callon and his colleagues (Callon 1986; Callon et al., 1991) and methods I have adopted on similar topics (Cochoy, 2021; Cochoy, 2022). I draw on contemporary work on the sociology of plastics (Hawkins, 2019; 2021) and its alternatives (Cochoy et al., 2022). I also draw on a body on research focusing on the various epistemic, economic, political and sociological processes that tend to produce ignorance even in the most scientific oriented settings (Frickel and Vincent, 2007; Heimer, 2012; McGoey, 2012; Dedieu, 2022; Knudsen et al., 2023). After describing the data and methods on which this study is based, I present the legal and professional rules as well as some specific rhetorical patterns that frame patent writing. As the study shows, patents are highly constrained by specific laws and rules: they must focus on utility, and only on utility, thus preventing moral concerns such as care for the planet from being part of the patenting process. They must also be generic, which prevents them from focusing on specific materials. These rules promote the unconscious, discreet and continuous proliferation of plastics in face mask patents, as well as the ignorance of their health and environmental impacts, at the risk of eliminating safer and more sustainable alternatives (Strasser and Schlich, 2020). The research reveals new patterns behind the production of ignorance, and thus new challenges that need to be addressed at the theoretical, technological and political levels, if we really want to move towards a healthier and more sustainable society.

Data collection and methods

A lot of work is being done to trace the presence of plastics in rivers and oceans (e.g., Ter Halle and Ghiglione, 2021), but such efforts take a downstream approach that neglects an upstream problem about which we don't know much: plastic components collected in outdoor spaces are hard to trace, both chronologically and spatially. If plastics are a threat, would it not make sense to address their proliferation both upstream and downstream? Would it not be appropriate to address the source of the problem rather than just its consequences? Hence the following questions: Where are the plastics in the environment coming from? Since when? How do plastics end up in everyday objects? Who decides to use them? For what reasons? How does the technological embodiment of plastic evolve over time?

In their comprehensive history of facemasks, Strasser and Schlich (2020) recall that surgical masks have long been made of fabric, and that the filtration performance of such fabric masks was as good as that of contemporary polypropylene models. However, I would like to complement this historical statement with a more systematic and precise examination. For example, talking about cloth and fabric could be confusing, because several fabrics are in fact made of synthetic materials. A long-term collection of patents seems to be a good way to deal with this issue, since patents focus on the design of technical objects and thus provide innumerable details about their construction.

Thanks to the Google patent search engine and ad hoc scraping software, I have built up a collection of patents related to face masks. I focus on simple filtering face masks that can be used in both medical and general settings, without an external oxygen supply, to protect the wearer from various types of contaminants – germs and viruses, as during the Covid-19 crisis, but also gases or dust, as all sorts of masks have been used by laypeople for sanitary purposes. To this end, and based on preliminary research in the scientific literature, I focused on US patents: this state-based corpus provides greater homogeneity, is based on a single legal framework and patenting process, and avoids language problems that arise when looking at patents from an international perspective. I then retrieved all US patents with one or more of the following expressions in the title: cloth mask; disposable mask; dust mask; fabric mask; face covering; face(-)mask; face protection; face shield; face mask; homemade mask; medical mask; ppe[2] mask; protection mask; protective mask; respirator mask; respiratory mask; sanitary mask; disposable mask. I further reviewed the list of 1,837 patents obtained by this process to eliminate those items that did not fit our research objective – i.e., according to the above definition, I excluded shields and visors and masks with self-contained oxygen supply. I kept some gas masks, but only those that were not labeled as such in the title. I excluded masks for extreme cold, automobile or train driving, aviation use, oxygen supply, facial care masks, recreational use, mechanical face protection in sports or industry, firefighter masks, and animal masks. I also excluded mask accessories and mask manufacturing methods. According to these various inclusive and exclusive criteria, I ended up with a population of 615 patents covering the period from 1912 to 2022. This corresponds to a corpus of 3,604,498 words (i.e. an average of 5,861 words per patent). In the following pages, the reference year is the priority year, i.e. the year from which the patentees can legally claim their priority. For each patent, the scraping process retrieves the full PDF, as well as the description, claims, and citations given and received (in raw text format). It also provides rich metadata: patent title, assignee and inventor names, priority, filing, publication, and grant dates. I then enriched this metadata with additional information, such as the number of claims, the number of citations given and received, and several indexes measuring the number of words related to plastic and natural components, as well as the number of terms related to disposability and sustainability (see below).[1]

On patent writing

A "factural" rhetoric

However, before studying the content of patents and tracing the presence of plastics in them, it is important to know what such texts are, what they are about, what they have to say, and what matters they cannot deal with. Bruno Latour (2004; 2005; 2008) proposed to complement the classical notion of 'matters of fact' with the twin notion of 'matters of concern.' He did so to emphasize that contemporary 'things' are entities that combine objective and moral dimensions:

> where matters-of-facts have failed, let's try what I have called matters-of-concern. (…) For too long, objects have been wrongly portrayed as matters-of-fact. This is unfair to them, unfair to science, unfair to objectivity, unfair to experience. They are much more interesting, variegated, uncertain, complicated, far reaching, heterogeneous, risky, historical, local, material, and networky than the pathetic version offered for too long by philosophers. (…) "Facts are facts"? Yes, but they are also a lot of other things *in addition.* (Latour, 2005: 19-21).

A face mask, for example, is both a physical object – a matter of fact – and something that involves moral issues – the sense of caring for others, the preoccupation with its polluting character, and so on, i.e., matters of concern. According to Latour indeed, "a matter of concern is what happens to a matter of fact when you add to it its whole scenography, much like you would do by shifting your attention from the stage to the whole machinery of a theatre" (Latour, 2008: 38). Latour's matters of concern can (should?) even be extended to 'matters of care' (de Bellacasa, 2017), for at least two reasons: first, as Bellacasa explains, the notion of care implies a commitment to action; second, in my particular case, masks are obviously oriented to care, provided that we do not restrict the notion to health care, or rather, that we do not limit health care to the human body, but also apply it to the well-being of the whole planet.

The problem with patents on facemasks, however, is that patents are texts that, given their legal and technical characteristics, avoid 'matters of fact,' 'matters of concern' and 'matters of care.' Patents are not really about introducing (arti)facts; they are rather about presenting innovations publicly. As such, a patent is more about disclosing the idea behind a technology, than exhibiting this technology per se (Biagioli, 2006). What a patent protects is a concept, not a manufactured good. The particular application of such concept and the means employed to materialize it have therefore better to remain vague. In other words, a patent deals with the following dilemma: it has to be specific enough to differentiate the invention it presents from previous patents and avoid litigation, yet broad enough to secure its industrial and commercial application, and prevent it from future competition. Such writing style protects the patentee, because varied material applications may still refer to the idea behind a single patent. It also increases the chances of having the patent implemented: a manufacturer will prefer to rely on patents that provide some freedom about the means to industrialize them. In other words and as surprising as it may seem for an institution about technology, patents are not so much about matters of fact, but about technological ideas. Just like Cori Hayden's generic drugs (Hayden, 2022), a patented solution has to be the same and not the same: is has to be both faithful to a given patent and a specific application of this same patent. Therefore, it is largely against the interest of patents to describe what materials should be employed to apply them, although it is not strictly prohibited for patentees to do so (and it may be best for them to do so, since suggesting appropriate means ensures the practicability of the proposed solution).

If patents are not really about matters of fact – except of course for patents aimed at describing particular materials –, neither are they about matters of concern or matters of care (Cochoy, 2021). In the United States, there has long been a legal debate about whether patent examiners or courts should reject or invalidate patents based on moral or ethical considerations. If in the early 19th century a "moral utility doctrine" (Enerson, 2004: 690) prohibited patents that conflicted "with the sound morals of society" (Enerson, 2004: 685) such as slot machines, this doctrine has since been abandoned. As Enerson puts it: "moral and ethical concerns should not be considered in determining the usefulness of an invention in the United States (…) courts and patent examiners should ask only whether a particular invention may be useful to the public, not whether the public should use such an invention" (Enerson, 2004: 688). As Enerson concludes, citing Schapira (1997: 171-172), "most patent attorneys in the United States believe that the 'American view' is that 'morality (...) should have nothing to do with patents.'" As a result, contemporary concerns such as environmental protection do not fall within the scope of patents (except, of course, for patents specifically directed to devices for cleaning or protecting natural environments). In 2024, US patenting institutions still view patents as morally neutral, as mere technical devices designed only to stimulate the market, at the risk of ignoring their obvious political character in terms of underlying ethical worldviews, social impacts, and other multiple 'distributive implications' (Parthasarathy, 2017).

In fact, patent writing is highly constrained by patent law and institutions. To be patented, an innovation must be shown to be novel, non-obvious, and useful (Seymore, 2014). Patents cover the novelty aspect by showing the contribution of the innovation to the prior art. They thus refer to each other by allusion or direct citation. Non-obviousness means that a 'person of ordinary skill in the art' (PHOSITA) would not know how to solve the problem addressed by the invention. Last but not least, as mentioned above, the usefulness of the patent refers to a classical, selfish and narrow sense of usefulness: the patent should prove its ability to fulfill a local and particular function, and thus its immediate use; whether the patent is useful or harmful to society or the environment as a whole on the long run is outside the scope of patents. According to this logic, a novel mask can be patented because it filters germs better, even if the chosen solution obviously endangers the planet.

For all these reasons, the content of patents is neither real nor abstract; we could say that patents are *factural*, i.e. they are both factual/instrumental – they address material problems – and cultural: they present ideas for solving these problems, but also convey or raise concerns about their subject matter. This factural dimension is tightly constrained by patent law and the rules of patent offices (Myers, 1995). Based on these laws and rules, patents must focus on presenting plans and special arrangements that help perform a particular action. However, they are not concerned with describing the precise means of doing so (e.g., materials) or discussing the morality of that action (e.g., concerns). Thus, when considering how materials or moral concerns are addressed (or not) in patents, it is paramount to keep these constraints in mind. As we will see, in part because of the above constraints, such entities are rarely presented, and when they are, they appear in a particular way that I propose to discover. In other words, it is not enough to obtain statistics on the occurrence of materials in patents; these statistics should be closely related to the patent culture and, more importantly, to how such materials (matters of fact) and cultural dimensions (matters of concern/care) have evolved together in the patent genre as well as in society at large.

In this respect, the patent institution could be described as another framework that contributes to the production of ignorance. For example, Frickel and Vincent showed that standardized pollution assessment methods were unable to determine whether Hurricane Katrina had polluted Louisiana or not (Frickel and Vincent, 2007). François Dedieu showed how ignoring farmers' fraudulent use of pesticides helps the French food safety agency keep its assessment procedures unquestioned and thus protect its reputation (Dedieu, 2022). Similarly, following the rules of patent writing is the best way for patent writers to get their applications patented and avoid embarrassing debates. On the one hand, these constraints explain the longstanding and overwhelming disregard (or ignorance) of mask patents for material and moral concerns. However and as we shall see, these constraints are not absolute, but can be overcome by various means, the first of which are of a rhetorical nature.

Preferably [X]…

In the case of mask patents, I have to solve the following puzzle: how can specific materials or concerns penetrate a kind of discourse that tends to favor the adoption of generic and moral-free formulations? If I cannot immediately address the case of concerns, I can provide an answer for materials. To promote some materials in their texts, patent attorneys and engineers rely on two specific and ubiquitous rhetorical figures.

The first figure consists in coupling the mention of a specific use of materials with the adverb "preferably." Our corpus contains 1,256 different adverbs, used 109,126 times. In this list, "preferably" ranks 7th, just after very vague and frequent adverbs like "wherein," "not," "as," "also," "herein," "so," and even before such common adverbs as "about" and "only." It appears in more than half of the patents (52%). It is used 2,383 times, which is 2.1% of the total number of adverb occurrences. Even more interestingly, this figure places "preferably" at roughly the same level as "generally," which is used 2,311 times. This equivalence epitomizes the tension between specificity – indicated by "preferably" – and genericity – embodied by "generally." Preferably is thus a way of suggesting the use of a particular material, but also of presenting it as just one solution over several others, and thus respecting the generic nature of patents. See the examples below:

> A yolk 60 is typically placed on top of the face piece 10. The yolk is made of a semi-rigid material, preferably plastic. (US5592937A); Facial protection layer is (sic.) prevents dryness, and is preferably non-woven material. (US20170209719A1); Respirator face piece 10 preferably comprises three stiffening elements 20, 30, and 40, respectively, made of a lightweight material, preferably a moldable plastic, and more preferably polypropylene or glass filled polypropylene, which are held together by a thermoplastic rubber 50, preferably one that has polypropylene in it such as kraton, starflex or sanoprene. (US5592937A); On the outer surface, and attached thereto in any suitable manner is a non-porous sheet 22 of impervious material preferably polyethylene film. (US3170461A)

… (or) any other (suitable) material

A similar and complementary way to be specific while still respecting the generic nature of patents is to accompany the mention of a preferred material (presented as a pure option: see the use of "can be" or "may be") with a clause like "(or) any (other) suitable material(s)." Searching such clauses in the corpus with TXM[3] yields 124 matches spread over 63 patents, i.e. more than 10% of the entire collection, of which Table 1 gives examples:

Table 1. Pivot table for "or any other suitable material.

id	Left context	Pivot	Right context
US20210106853A1	the material M2 may be polybutylene terephthalate	or any other suitable material	). The different materials M1, M2 of the facepiece 12
US20220105369A1	The hook may be made out of plastic, metal, composites,	or any other suitable material	. The hook may extend from the third strap portion 140
US20220117335A1	The tubular members 310 and 312 may be made of plastic	or any other suitable material	. The tubular members 310 and 312 may be hollowed for passing
US20220312867A1	the valve-connected member 118 ca be manufactured of fabric, flexible plastic	or any other suitable material	as is known in the art which allows the exhaled air to
US20210352978A1	hard plastics, fiber reinforced plastics, carbon fiber, fiber glass, resins, polymers or	any other suitable materials	including combinations of materials

Zooming in on the full version of the last item of this list illustrates well the logic of which "any other suitable material" is a part:

> the elements that comprise the device 100 may be made from or may comprise durable materials such as aluminum, steel, other metals and metal alloys, wood, hard rubbers, hard plastics, fiber reinforced plastics, carbon fiber, fiberglass, resins, polymers or any other suitable materials including combinations of materials. (US20210352978A1)

This list shows the extreme caution of the patent's author in providing details about the material construction of his innovation, and all the tricks he uses to be specific and generic at the same time. Not only is everything presented as optional, but the optional character concerns both the proposed materials ("such as") and their full or partial use ("may be made of or may comprise"). The list addresses specific materials, but its length compensates for this specificity: no less than 12 items are listed. Moreover, most of these elements are themselves of a generic nature and presented in the plural, so that they offer a subsequent choice within the choice itself: the manufacturer can choose between wood or hard rubbers, but he will also be free to decide which wood or which rubber to use. The materials are listed without regard to their natural or synthetic character: "wood" comes between "metal alloys," "hard rubbers" and "hard plastics." What matters is not the specific nature of the materials, except that they are all equally capable of belonging to the generic category of "durable materials," in the sense of solid, long-lasting (in French, durable also means "sustainable," which is of course irrelevant here: all materials are considered equal, provided they perform the same function). Last but not least, despite the impressive care taken to mitigate all possible differences between the listed materials, the author ends with the formula "or any other suitable materials," followed by a precision: "including combinations of materials."

We now understand how materials are addressed in patents and how they can penetrate this literature: materials enter patents provided they perform a certain function, and only that, are generic in nature, and are considered as one option among many equivalent others. "Preferably" pushes a solution while making it optional; "or any other suitable material" softens the suggestion of particular materials by pointing to alternative solutions. All in all, these two tropes are about nudging manufacturers: according to the generic nature of patents, it leaves the choice of materials completely open ("or any suitable material") while still recommending certain solutions ("preferably"). With this rhetoric in mind, it becomes possible to understand, measure, and analyze how plastics have been incorporated into the patent literature.

Plastics as one material among many, and materials as one theme among several others

We will be able to better evaluate the presence of plastics in patents if we get a larger view of their place among all the other aspects that patents are about. To get such a view, I propose to first subject the vocabulary of my corpus to a descending hierarchical classification using the Iramuteq software.[4] This method divides the whole corpus into text segments (identified by punctuation). It then builds a presence/absence table that crosses the text segments with the entire vocabulary of the corpus. The goal of this table is to bring together text segments that tend to contain the same words[5] into sets called "classes." A word's membership to a given class is established according to its independence, as measured by a Chi-square test. Using this procedure, the software is able to identify the different topics covered in the corpus and the words that are most associated with each topic.

As can be seen in the caption on the left, seven classes emerge from the classification. This analysis provides no surprises, but rather a synthetic view of what mask patents are all about.[6] Facemask patents are technical documents that describe the purpose and field of an invention (class 5: "scope," "description," "understand," drawing…") and provide detailed information about its technical construction (class 4: "fold," "edge," "pleat," "bottom," "line…"). An interesting feature of facemask patents is that they cover a cyborg-like aspect: these inventions are about finding the technical means to closely articulate a technical device and a human body. Thus, facemask patents focus on

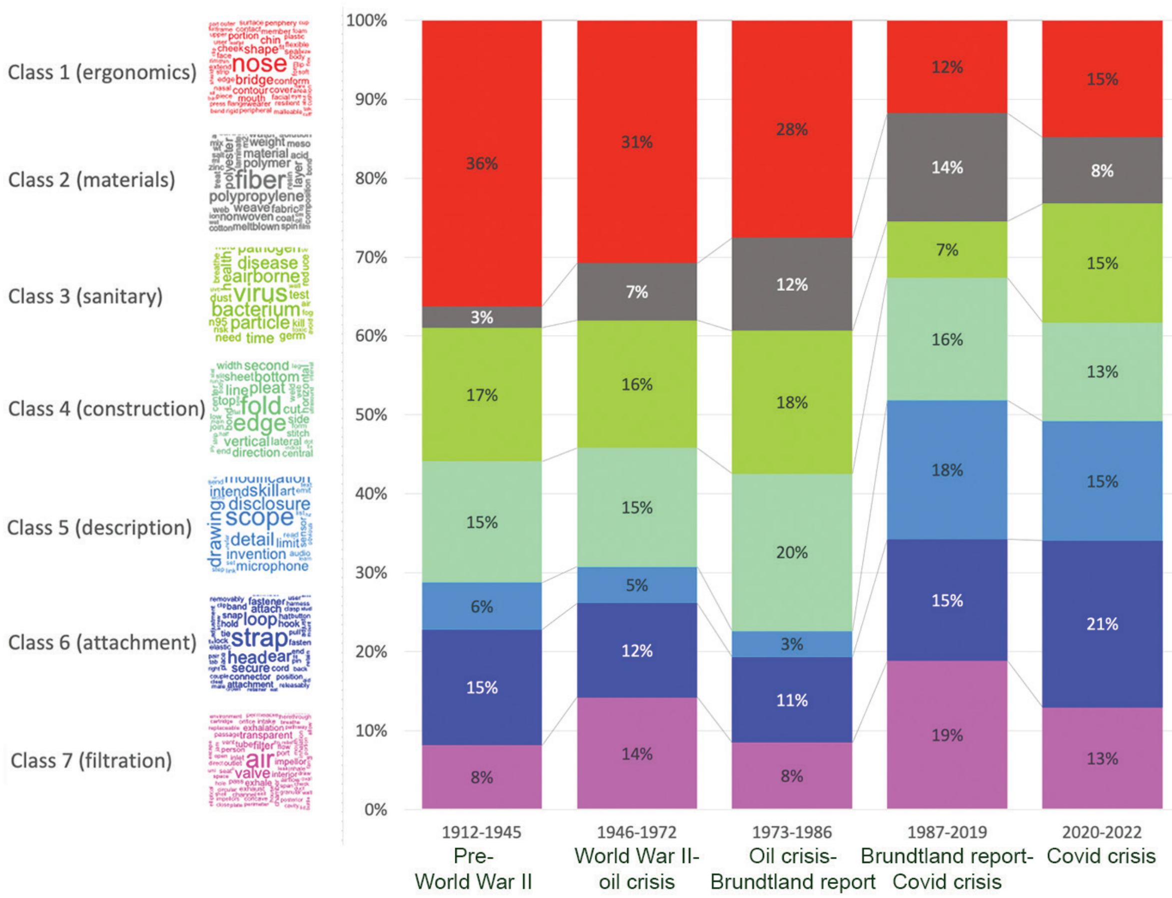

Figure 1. Reinert classification of the corpus.

ergonomic issues (class 1: "nose," "bridge," "shape," "chin," "contour") and especially on the best way to attach the mask to the user's face (class 6: "strap," "loop," "ear," "secure," "attach"…). A key concern is obviously the hygiene performance of the device in terms of combating various substances (class 3: "virus," "bacterium," "airborne," "particle, "disease," "pathogen"…) and thus its functional filtration devices (class 7: "air, valve," "filter," "transparent, "exhale"…). Here, the concern for health is clearly oriented toward a sense of care, even if it is limited to the human body. Of course, the materials used to achieve these different objectives are present (class 2: "fiber," polypropylene," "polymer," "material," "weave," "polyester"…), but the share of this class is rather discreet: it represents 11.2% of the total, a rate which is only slightly higher than the share of the "description" class (10.9%), but far behind other classes such as sanitary aspects (16.3%) and ergonomics (18%). This modest position of materials in patents on masks confirms that such patents tend to avoid being too specific in terms of manufacturing. However, it can be noted that words related to plastics (polypropylene, polymer, polyester, non-woven...) are among the 10 most representative terms of class 2, whereas other materials such as "carbon" or "cotton" appear only in 18th and 23rd place respectively.

The right part of the figure shows how the share of the seven classes has evolved over the history of mask patents. For better clarity, I made the calculation for five different periods related to events that affected the plastics industry: before World War II, after World War II until the oil crisis, from the oil crisis to the Brundtland Report, which popularized the idea of sustainable development (Borowy, 2013), after the Brundtland Report, and finally the Covid-19 period. As can be seen, the main evolution concerns ergonomic aspects, which tended to decrease, probably due to the emergence of a standard design for facemasks. The share of descriptive aspects increased, mostly due to the increasing average length of patents over the years (roughly from a few pages in the early

20th century to often ten or more pages today). Most other aspects have not changed significantly, reflecting the persistence of the underlying problem: a mask is a mask, and a patent on a mask has to address issues of construction, attachment, and filtration, no matter when. However, materials are an exception: until the Covid-19 crisis, the share of materials increased continuously, from 3% to 14%. This evolution shows a tendency for patents to show a greater concern for materials over time, despite the need for patents to have a generic character that requires/favors technical vagueness. The development of plastic materials after the war certainly explains this shift, but I still have to check which materials have been put forward and why in the most recent periods, notably after the oil crisis, the sustainability turn and the Covid-19 pandemic.

Presence and evolution of materials and concerns in mask patents

In order to document these aspects, I propose to track the presence of key materials and concerns and to follow their evolution. To this end, I have constructed two pairs of indices, one contrasting natural vs. plastic components and another contrasting disposability vs. sustainability concerns (i.e. health preoccupations related to caring for the planet). The idea is to compile the occurrences of words related to each term and study the chronological evolution of the resulting indexes, as well as their level in specific patents. For this purpose, I used the TXM software, a powerful textometric tool designed to track specific items in a given corpus (Heiden, 2010). With TXM, it is possible to count specific words or linguistic structures (e.g., the combination of any adjective with a given word) and to specify the results according to the underlying metadata (e.g., the publication date of the documents that make up the corpus under study).

The first pair of indexes focuses on materials and contrasts natural components (excluding metals and minerals) with plastics. I constructed the plastics index based on the tables of thermoplastics and thermosets provided by Encyclopedia Britannica:[7] acrylonitrile-butadiene-styrene; cellulose diacetate; epoxies; polyethylene; phenol formaldehyde; polyacetal; polycaprolactam; polycarbonate; polyester; polyetheretherketone; polyethylene terephthalate; polymethyl methacrylate; polyphenylene sulfide; polypropylene; polystyrene; polytetrafluoroethylene; polyurethane; polyvinyl chloride; urea and melamine formaldehyde. I supplemented this list with more general terms, such as plastic(s) and nonwoven(s), on the assumption that almost all contemporary nonwoven textiles are synthetic, and commercial or common names for synthetic fibers, such as acetate, acrylic, elastane, lycra, lyocell, nylon, polyamide, rayon, spandex, and viscose.[8]

For the natural fiber index, two lists were combined: a list of vegetal fibers (bamboo; banana; barley; coconut; cotton; flax; hemp; jute; kenaf; linen; palf; pineapple; ramie; rattan; rice; straw; vine; wheat; wood) and a list of animal components (alpaca; cashmere; chitin; chitosan; collagen; keratin; leather; mohair; silk; wool).[9] To these lists, I added the more general terms of "natural fiber(s)," "natural rubber(s)" and "natural adhesive(s)" found in the patents. I did not approach the opposition between synthetic and natural materials with the presence of "cloth" or "fabric" elements, because these words say nothing about the nature of these textiles.

The second pair focuses on concerns contrasting disposability and sustainability. I found these terms not by examining an external list, but by counting the number of "*able" adjectives present in our corpus, i.e. words that end with the suffix "able" and are related to disposability and sustainability, respectively: flushable and disposable for disposability; autoclavable, biodegradable, cleanable, compostable, durable, launderable, machine-dryable, machine-washable, microwavable, non-disposable, reusable/recyclable, recyclable, rinseable, sanitizeable, sterilizable, sustainable, and washable for sustainability. As can be seen, if the concept of sustainability is a recent one, other related terms are much older and thus help to trace the concerns that have become associated with sustainability over the long period.

Thanks to the TXM software, I counted the occurrences of each word for each category per five-year periods and compiled the results. The level of each category is summarized with an index that gives the number of occurrences per year per thousand words for each five-year period (this ratio helps to neutralize the varying size of patents as well as the uneven number of patents per period). The graphs below show the corresponding results.

Natural material vs. plastics

Unsurprisingly, natural elements came first and exclusively: one had to wait until after World War II to see plastics included significantly in facemask patents. Prior to that time, only materials based on vegetal or animal sources were available and cited in patent texts. This was a very modest presence: during this period, 41 words represented natural elements out of a total of 54,853 words, a rate of 0.7‰. Cellulose and cotton accounted for 78% of this total, meaning that the choice of materials was limited and thus not really an issue, all the more so as patent texts were short during this period – with an average of 1,714 words per patent before the Second World War, in sharp contrast to the average of 6,090 words of the subsequent period. Patents thus focused on design issues and tended to avoid material details, as the patent logic described above implies.

A single tiny exception to the discreet hegemony of natural materials occurred: in 1934, just one plastic-related word, "acetate," appeared in just one patent. Paradoxically, this patent (US2038310A) and this word deserve attention despite their exceptional character. The patent presents a simple "surgical mask" whose purpose was very similar to today's devices, since it was "not only protect[ing] the operating working field from contamination, by nose and throat discharges or perspiration during an operation, but also, in certain circumstances, (…) protect[ing] the operation against similar discharges by the patient" (US2038310A). In its description, this patent alludes to possible components, along with the careful rhetoric aimed at suggesting the use of some components without making them mandatory that I described above:

> In the illustrated embodiment of the present invention, there is shown a face mask or shield 5 which may be made of any desirable or suitable fabric or cloth, and which, to meet the exigencies of certain circumstances, may be made of a cellulose derivative, such as cellulose xanthate, nitrate or acetate (US2038310A).

Interestingly, the patent refers to available materials such as "fabric" or "cloth" – i.e., materials made of natural fibers at the time – but it also alludes to the possibility of relying on "a cellulose derivative, such as cellulose xanthate, nitrate or acetate." These materials played a key role in the transition from natural to synthetic materials. In particular, acetate cellulose, also known as "rayon," is one of

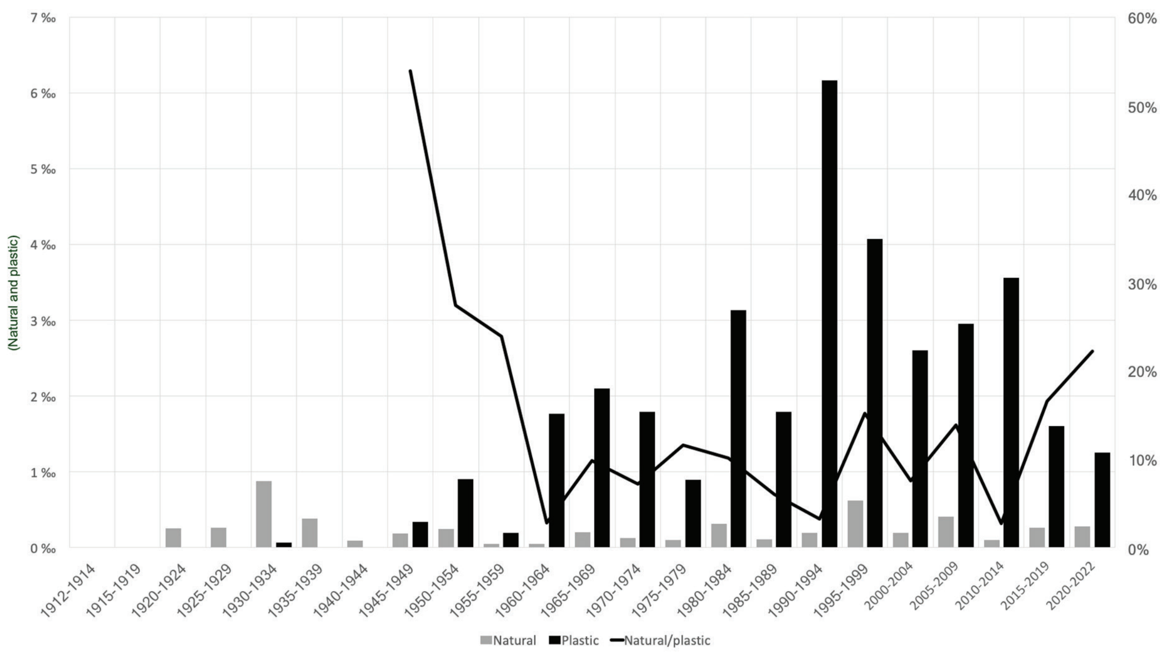

Figure 2. Natural vs. plastic components.

the very first synthetic fibers invented in human history. It was first developed in 1895, but it was not until 1924 that it was converted into a fiber and marketed by the US company Celanese (Kaufman, 1993). Significantly, this product was derived from natural cellulose extracted from cotton and wood pulp and then transformed with various solvents and additives, and even today, it is very difficult to distinguish rayon from cellulose in samples (Cai et al., 2019). In his detailed paper on the history of rayon, George B. Kaufman (1993) describes it as a "semi-synthetic" fiber, given the partly natural and partly synthetic character of this material based on vegetal sources and chemical components and processes. It is noteworthy that Kaufman concludes his review with a paragraph entitled "Ecological and Pollution Considerations" –just a few years after the Brundtland Report brought sustainability concerns to the forefront. In this paragraph, Kaufman, while lamenting the large amount of water needed to make rayon, also points out that no solvent is lost in the manufacturing process and lists the following benefits:

> Since rayon is made from trees, no petroleum is used in manufacturing the polymer, and much of the energy used for separation and purification of cellulose is derived from pulping by-products as energy sources. These last two factors give rayon a favorable position compared to completely synthetic fibers with regard to the total energy required for fiber production. (Kaufman, 1993: 892).

Rayon clearly served as a transition from natural to synthetic products. The latter began to emerge in the interwar period: Polyvinyl chloride was invented in 1927, polystyrene and nylon in 1938, and polyethylene in 1942. However, one had to wait until after the Second World War to see the boom of the plastics industry: between 1950 and 1970, the production of oil-based plastics increased twentyfold to more than 25 million tons, of which 8 million tons were produced in the United States alone (Chalmin, 2019). Throughout these developments, the plastics industry never stopped pushing its products (Mah, 2022), and these efforts obviously contaminated the patent literature. The flow of plastics entered our corpus with a slight delay indeed, along a growing trend that peaked in 1994, with a ratio of 10.6 plastic-related words per 1000 words, i.e. more than 1%! However, the most "plasticized" patent was granted in 2010, as shown by its abstract:

> The purpose of the invention is to provide a surgical mask with sufficient antibacterial properties, by uniformly manifesting on the surface of nanofibers a functional material with antibacterial and antiviral properties. The problem is solved by a mask with a functional material which comprises a nanofiber containing at least one base polymer selected from a group consisting of PVA, polylactic acid, fibroin, chitosan, chitin, nylon 6, nylon 6,6, nylon 9T, nylon 610, polyamide, polystyrene, polyacrylonitrile, polyethylene terephthalate, polyvinyl chloride, polyurethane, polyester, zein, collagen and methoxymethylated nylon, and at least one functional substance selected from a group consisting of catechin polyphenols, persimmon tannin polyphenols, grape seed polyphenols, soybean polyphenols, lemon peel polyphenols, coffee polyphenols, phenylcarboxylic acid, ellagic acid and coumalin, and having a diameter of 1 nm to 2000 nm. (US20130291878A1)

This patent contains a very high number of plastic-related words (282), with a rate as high as 16‰.[10] In a sense, this focus on materials is surprising, as it seems to contradict the generic aspect of patents inherent to the patent institution (see above). However, when we read the patent, we understand that if this particular patent abandons the dominant avoidance of materials in patent writing, it is because in this case plastics are precisely the resources whose combination guarantees the claimed function, i.e. the provision of "a surgical mask with sufficient antibacterial properties." In the patent, materials are presented as the means to achieve the desired function. In this respect, all materials suitable for this purpose are acceptable: the patent cites plastics because they are presented as necessary to achieve the targeted objective. However, it is important to note that plastics are not cited exclusively. Let us look at the very long list of materials mentioned. In this list, natural elements such as "chitosan," "chitin," "zein," "collagen" are jumbled with synthetic plastics, without any sense of hierarchy or preference, i.e., the cited synthetic or natural materials represent equivalent solutions to perform the function in question. In addition, the list recommends the use of polyphenols, a type of molecule extracted from various plants, as the mention of "persimmon tannin," "grape seed," "soybean," "lemon peel," and "coffee" shows well.

In fact, the patent manages to cite materials while fully respecting the logic of patenting. It does so by adopting a subtle strategy consisting in being specific as a way of not being so. In fact, a closer look at the list shows that only two *types* of materials are recommended, and then detailed with two long lists of possible solutions, so that the ways to industrialize the patent remain open: "The problem is solved by a mask with a functional material which comprises a nanofiber containing at least *one base polymer* selected from a group consisting of [set of examples No. 1] and at least *one functional substance* selected from a group consisting of [set of examples No. 2]." Suggesting a "base polymer" – i.e., a general category of material that includes many specific sub-units - is clearly another way of being specific without being so. More importantly, the emphasis is exclusively on utility, as required by the patent genre: materials are cited for their ability to perform the targeted function, and this only: "The problem is solved by a mask with a *functional material* comprising a nanofiber containing at least (...)." This is done without any consideration of the source or the side effects of the chosen materials. This patent illustrates well how plastics came to be included in patents: they were introduced "under cover," as technical means for a given purpose, rather than as entities deserving examination in themselves.

In general, if face mask patents have long ignored the environmental and health hazards associated with plastics, it is because they have considered them as solutions available on the market, be they generic products widely produced by the chemical industry (polypropylene, polyester, polyethylene, etc.) or branded products proposed by large companies (nylon, lycra, etc.). Significantly, the expression "available from" followed by the mention of a specific company appears no less than 100 times in the entire corpus – see for example: "The microporous membrane is made by extruding a mixture of polytetrafluoroethylene (PTFE) (commercially available from du Pont under the name TEFLON ®)" (US20090211581A1). It is as if mask designers follow the implicit assumption that everything that is commercialized is legal and approved. The patent writer, as a mere user of commercial components, thus considers them, if not risk-free, at least free of concerns he or she has to worry about. Indeed, the process of invention is not just about creating things from scratch; it is largely about buying and combining external parts (Cochoy, 2016). This market side of invention distributes responsibilities among different actors. If the fragmentation of standards and regulations dilutes the assessment of hazards in the cases of informed consent procedures (Heimer, 2012), pharmaceuticals (McGoey, 2012) or pesticides (Dedieu, 2022), the externalization of concerns associated with commercial components largely contributes to further deepening the production of ignorance.

Now, if patents are largely indifferent to the nature of materials beyond their functional character, how can we explain that plastics have come to dominate natural components in facemask patents, when some natural elements seem to have the same functional properties as their synthetic counterparts (Strasser and Schlich, 2020)? Looking at Figure 2, we get the impression that the level of natural elements remained stable while plastics invaded the scene: even if the chosen indices are not really comparable, the rate of plastic-related words is significantly higher than that of natural ones, and more importantly, it experienced a clear increase from 1945 to the mid-1990s, even if it slowed down slightly during the oil crisis. More precisely, before the Second World War, only one patent mentioned only one plastic material. By contrast, 61% of the patents with a priority year between 1945 and 1972 mentioned at least one plastic component; this rate increased to 85% for the period 1973-1986 and decreased only slightly thereafter, with 82% between 1987 and 2019 and 76% for the Covid-19 crisis. Nevertheless, the facts that plastic-related words decreased after the 2010-2014 periods and that a quarter of recent patents do not mention plastics seem to be encouraging developments… even if one may wonder if such a decrease is not due to manufacturing routines: when solutions

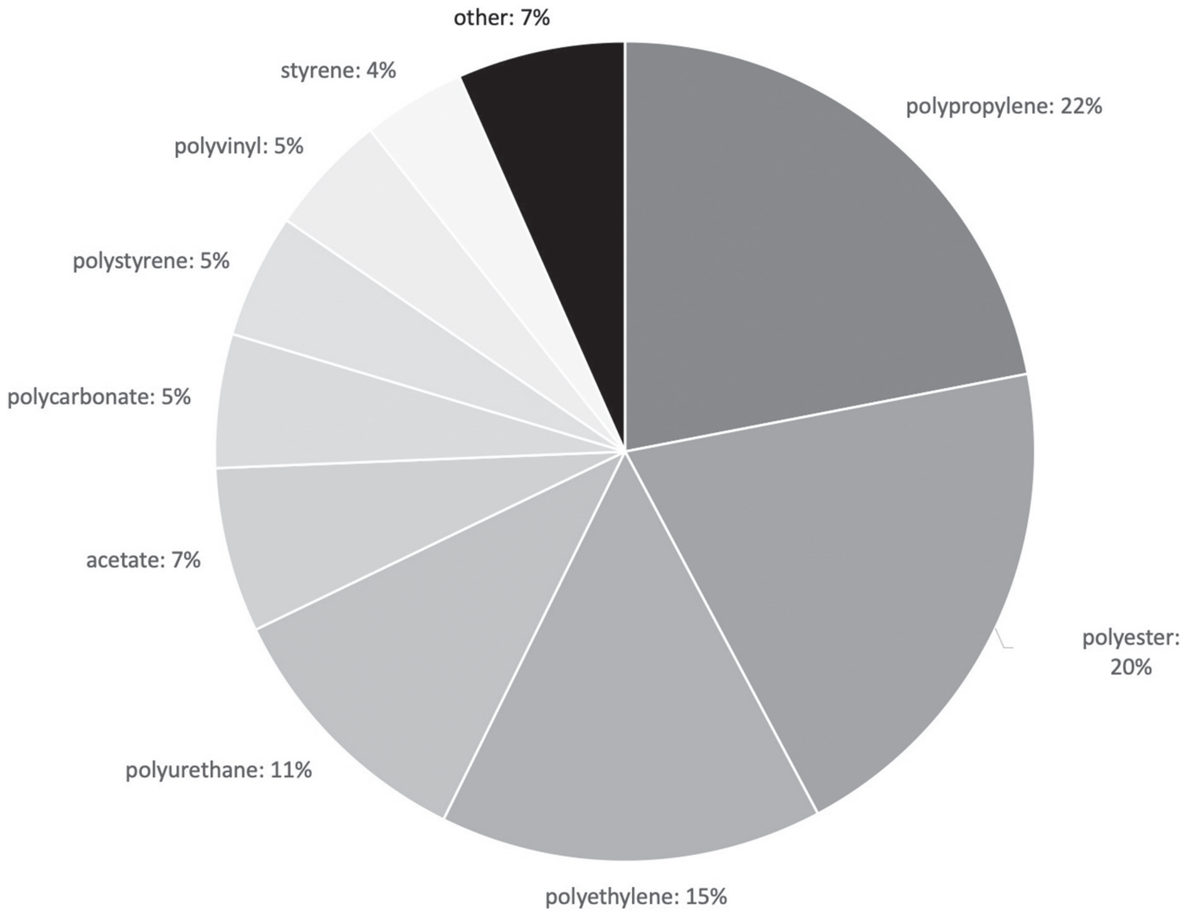

Figure 3. Plastics present in facemask patents.

become standard, there is less need to invoke them. Overall, the mask patents became full of plastics… and full of all kinds of plastics, as the pie chart below shows (Figure 3), even if polypropylene, polyester and polyethylene clearly dominated the corpus in the end, with the three of them representing 57% of the total.

To understand the evolution of the natural and plastic components, a better solution is to look not at these components per se, but at their respective shares. To this end, I have calculated the natural/plastic ratio for each five-year period: see the black curve in Figure 2 and the right axis. If the ratio itself is to be taken with caution (because they deal with different issues, the natural and plastic indices are not fully comparable), the evolution of this ratio is significant. Over time, we see that the share of natural components experienced a sharp decline from 1945 to the 1960s, and then remained at a low level until the 1960s. This corresponds to the plastic age. However, as indicated by the dotted polynomial trend curve, it seems that the recent tendency is more favorable for natural components, even if their comeback is not as fast as their previous decline. In other words, it is possible that the contemporary concern/care for the environment is penetrating the patent world, despite its institutional negligence for moral and ethical reasons.

Disposability vs. sustainability

A similar approach can be used to trace the evolution of value concerns such as disposability and sustainability. Disposability is rather a characteristic that reflects a lack of concern, a sense of carelessness, an immediate preference for convenience and practicality, and a disregard for the long-term consequences of such actions. The preference for disposability is a distinctive feature of late twentieth-century presentism (Hartog, 2015; Hawkins, 2018). As such, disposability is intimately linked to plastic, a material of which 49% goes into single-use items (Ogunola et al., 2018) and 40% is consumed by the packaging industry (Plasticseurope, 2020).

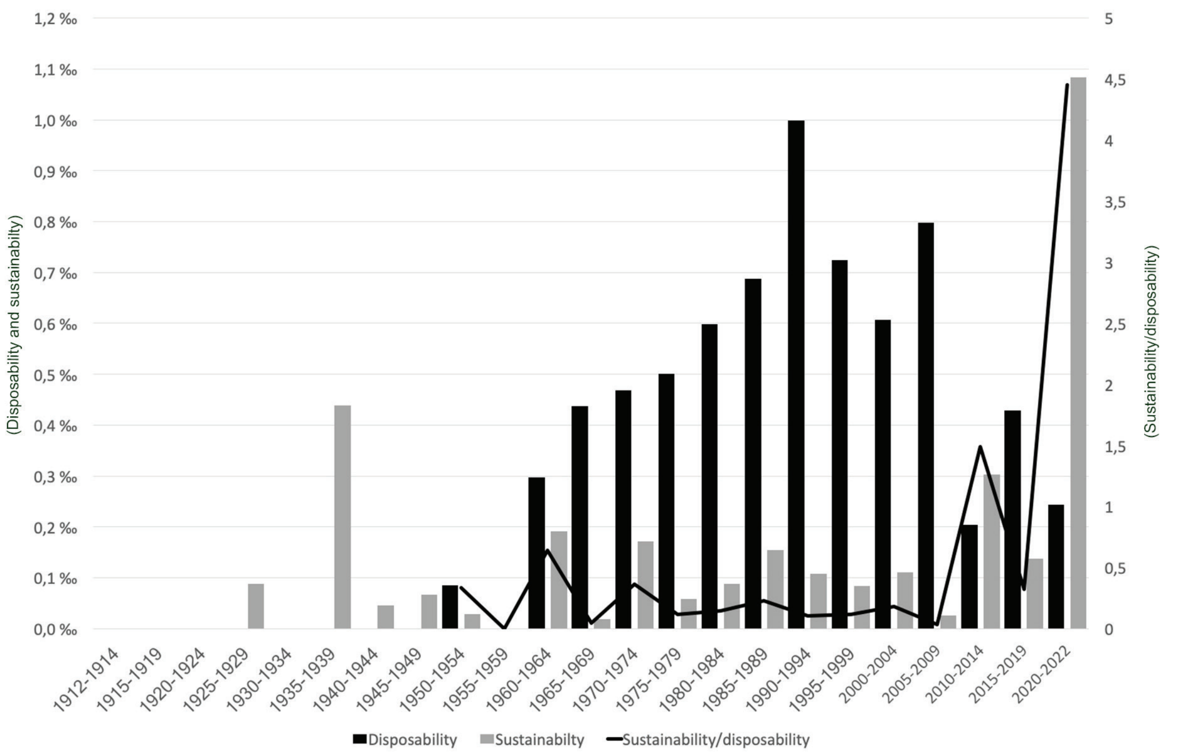

Figure 4. Disposability vs. sustainability.

To say that something is disposable is triple hypocritical. Firstly, it means that the disposable could be used otherwise, whereas in fact the object must be disposed of, since disposable goods are generally designed for single use only. Secondly, the claim of disposability is meaningless, since everything is disposable in some sense, so that one might wonder whether the adjective "disposable" has not long since become an (unintentional?) euphemism for plastic and, as far as patents are concerned, a way of presenting the material content of an invention without having to be specific and without violating the generic requirement of patent writing. Thirdly indeed, disposable qualifies objects that are mostly made of plastic and should therefore not be disposed of. Instead, disposable and (bio-)degradable should be synonymous, whereas in most situations it is exactly the opposite that applies.

Significantly, the plastic and disposable index curves have the same profile; in fact, these two curves are statistically correlated (r = 0.86). The terms "disposable/flushable" appear in 37% of the total collection of facemask patents. In addition, "disposable" appears in the title of 34 patents. In contrast, "reusable" appears in 20% of the patents and in the title of only 15 patents. It should be noted that the oldest occurrence of "reusable" is

id	Year	Left context	Pivot	Right context
US20150075532A1	2012	corporations are being driven to produce more	sustainable	and environmentally safe products through government regulations, by institutional investors
		hospitals and healthcare industries may be made from	sustainable	, environmentally friendly bioplastic resins and may be safely disposed without further
		tubing made from bioplastic resins. Environment and	sustainability	have become increasingly important factors in the design and specification of medical
US20210164138A1	2018	biodegradability which is of key importance for the	sustainable	use in disposable or single-use products such as hygiene articles
US20200323292A1	2019	inorganic antibacterial agents, the high efficiency and	sustainability	of the organic antibacterial agent, the safety and heat resistance of
US10912959B1	2020	adjustable face sizing, and made of	sustainable	, renewable, eco-friendly bioplastic material. 2.
US20210299489A1	2020	More specifically, there is a need for	sustainable	, re-usable, and breathable face masks
		transmission of viruses and pathogens, but is	sustainable	, re-usable, light-weight, and more breathable than the prior art
US20210316170A1	2020	provides an additional benefit in that it is	sustainable	and not quickly disposed of as environmental waste
		use and disposable, which is not environmentally	sustainable	. An embodiment of the face shield may be designed to be
US20220110378A1	2020	der Waals forces. The materials may comprise	sustainable	recycled materials. The face mask device is configured to fit over
		the invention 's mask devices will comprise	sustainable	, non-toxic alternative chemistries for water repellency purposes
		feel for the user, all in a	sustainable	configuration.
US20230014391A1	2020	made from biodegradable materials, recyclable materials,	sustainable	materials, and the like
US20220015474A1	2020	production, mild virucidal conditions, reusability and	sustainability	make HLIG a promising daily-use tool amid the pandemic.
US20220142268A1	2020	flexibility, breathability, washability, and	sustainability	, and does not incorporate the downsides of molded structures
US20220110378A1	2020	and preferably a renewable, recycled, or	sustainably	sourced synthetic fabric or biodegradable fabric
US20220240605A1	2021	of antiviral cellulosic fibers is poor and not	sustainable	. Therefore, biocidal masks based on cellulosic fibers often include

Table 2. Pivot table of "sustainab*" words.

from 1995, and that the use of this term is mostly concentrated in the most recent patents, as shown by an average date of 2016.

The late emergence of reusability is confirmed by the rise of sustainability-related notions of which reusability is just one particular component. After occupying a marginal position until the mid 2000s, with a rate always lower than 0.2 ‰, except before World War I (due to a 1937 patent, US2149067A, which presented at length "A washable and sterilizable surgical mask"), sustainability made a significant entry from the 2010s, to the point where it overtook disposability during the Covid-19 crisis.

In parallel, the presence of disposability declined in the recent period, possibly partly because it has become controversial, partly because it is now a routine, taken for granted and implicit feature of such goods. This evolution is evidenced with the profile of the sustainability/disposability ratio which was above 1 in 2010-2014 and jumped to 4 after the pandemic (see the black curve in Figure 4).

It is possible to get a better idea of such stakes by looking at the appearance of the words "sustainab*" and "toxic*" in patent texts. Developments related to sustainability (in the strict and contemporary sense of the word) have appeared only recently, long after the 1987 Brundtland Report that introduced the term, and only in a very limited set of 12 patents. The first mention dates from 2012 (US20150075532A1); the next ones appear in 11 patents that received their priority in 2018 and subsequent years. There are 18 mentions in these patents (see Table 2). This presence should not be overestimated. Not only are sustainability terms rare and recent, but they are also limited to the patent description and are therefore absent from the claims. To date, no facemask patent has been issued with "sustainable" in the title.

The way in which "sustainab*" words appear in patent texts reveals the processes by which social

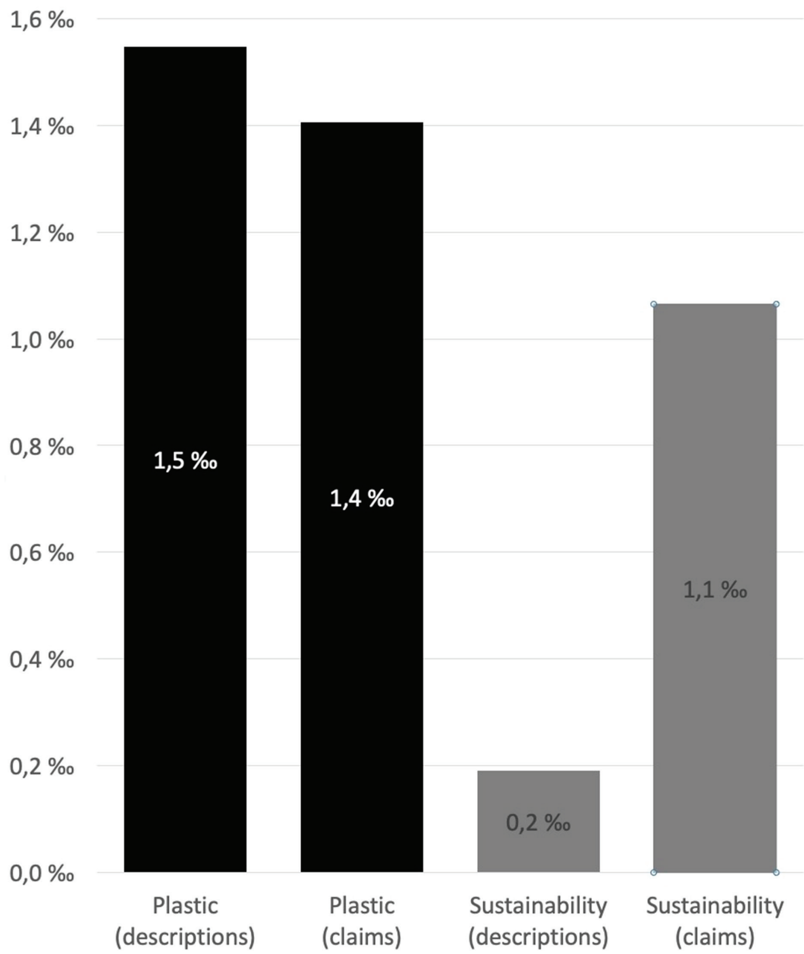

Figure 5. Plastic and sustainability in descriptions and claims.

and moral concerns are (or could be) incorporated into patent literature. Initially, such a shift seems to rely on direct references to external social developments. The 2012 patent alludes to pressures for sustainability coming from "government regulations" and "institutional actors." "Corporations are being driven to produce more sustainable and environmentally safe products": implicitly, if such pressure exists, responding to it falls within the scope of patent texts that are simply about producing useful objects. Sustainability is transformed from a morally remote concern – i.e., a concern irrelevant to patent writing – into a useful, material, and local property – a caring feature – that helps to solve contemporary needs. It is all the more significant that the most common form of "sustainab*" terms is not sustainability itself, but the adjective "sustainable." If we consider "sustainably sourced" as the equivalent of "sustainable," we count 14 occurrences of the adjective in 18 "sustainab*" words, i.e. 78% of the total. In its adjectival form, the concept of sustainability is transformed into a material, mechanical property, just like other similar qualities, such as "renewable," "reusable," "breathable," or "lightweight," with which it is often associated. In fact, sustainability is more often used as an objective property than as a concept: it appears as a twin to other similar properties such as "reusability," "flexibility," "breathability," and "washability." Incidentally, making sustainab* words part of longer lists of similar words is a third way of shifting sustainability from a moral concern to an objective property, or rather of hybridizing the two: with such lists, the moral concern becomes useful, and useful properties acquire some morality.

By the way, the shift towards sustainability is accompanied by the introduction of new materials, including "bioplastic resins" and "bioplastic material." Plastics are still there, but they are not the same. It should be noted, however, that bioplastics appear in only two patents: the US20150075532A1 patent (priority year: 2012) and the US10912959B1 patent (priority year: 2020), two patents that clearly allude to sustainability. The question remains whether this drop of sustainability in an ocean of classic plastics can lead to a more significant evolution.

To answer this question, it is possible to contrast the presence or absence of the four terms discussed so far (natural and plastic components, disposability and sustainability in the broad sense) in descriptions in claims (see Figure 5). Recently, the now familiar notion of "greenwashing," i.e. the promotion of corporate efforts to achieve sustainability goals far beyond what is actually done, has been supplemented by the twin notion of "greenhushing," i.e. a symmetric strategy consisting of silencing corporate sustainable practices, along the hypothesis that publicizing such efforts could attract the attention of activists at the risk of additional pressure and bad reputation (South Pole, 2022). Such caution is likely encouraged by the fact that the realization of sustainability policies, far from being obvious, relies on multiple and therefore controversial configuration practices (Lippert, 2015). It appears that facemask patents are not immune to greenwashing. Above, we signaled that sustainability concerns are quite rare in patents, although some clever rhetorical techniques have helped to introduce such concerns that were a priori illegitimate in this literature. However, Fig. 5 shows that, apart from their overall rarity, sustainability-related terms appear much more frequently in the claims than in the descriptions (5.5 times more), i.e. in the part of the patents that deals with their public objectives rather than their technical construction. As far as plastics are concerned, it seems that facemask patents also reveal the presence of another figure that we could call 'blackhushing,' if we take black as the color of oil, that is, plastic (Hawkins, 2011). As we have seen, facemask patents have increasingly incorporated plastics as part of their construction over the years. However, these materials are somewhat more present in the descriptions than in the claims, as if patent writers found it preferable not to insist too much on such components. However, this 'blackhushing effect' is very modest, which shows once again how little the patent institution cares about materials and their possible effects beyond their functional efficacy.

Toxicity

A final way to approach the attitude of facemask patents in terms of sustainability concerns is to focus on how they deal with toxicity issues. As noted in the introduction to this paper, facemasks are ambivalent in this regard: their purpose is to combat toxic substances such as dust, germs, vapors, gases, or viruses, but they often present themselves as toxic commodities, at least to the environment. As far as toxicity is concerned, a mask is a double pharmakon: it is a remedy against external toxicity, but it is also a poison because of its own internal toxicity. It is possible to assess the importance of these two opposing dimensions by looking at how the adjective "toxic" appears in the text of the patents. In the corpus, this adjective is cited 129 times. It seems that 89.2% of these citations refer to the external toxicity (the remedy side), while only 10.8% of them refer to the toxicity of the mask itself (the poison side). These rare mentions are made in only 8 patents, and apart from US4141703A – a 1976 patent that states that "it is made of materials that are not toxic to the skin" – and US20100239625A1 – a 2007 patent that examines possible legal biocides, even if some of them are toxic – the remaining six patents were all published between 2018 and 2021. The patent that is most concerned with the toxicity of facemasks is US10912959B1, a 2020 patent. This patent has several objectives:

> The invention relates generally to respirator oxygen masks, and more specifically to a reusable respirator oxygen masks with openings for speaking, eating, and drinking purposes, while still protecting the user by filtering air through the mask. Furthermore, a respirator oxygen mask having an exhale inhale breathable filter, adjustable face sizing, and made of sustainable, renewable, eco-friendly bioplastic material (US10912959B1).

Sustainability comes across as one objective among others, as if the author thought that concern/care for the environment (providing a "reusable respirator oxygen mask"… "made of sustainable, renewable, eco-friendly bioplastic material") would be all the more acceptable if it were combined with more traditional functional objectives ("openings for speaking, eating and drinking"; "protecting the user by filtering air through the mask"). More interestingly, the choice of sustainability is clearly linked to a criticism of the toxicity of previous plastic-based solutions:

> Currently, traditional cloth masks have fibers that are made from petroleum polymers which are toxic to humans. While other masks, such as oxygen masks or dust and bacteria filtering masks are made from toxic petroleum base polymers such as PET or PETE (polyethylene terephthalate). PVC is also another typical component of respirator masks, but it is also toxic to the user's health and environment. (US10912959B1).

This patent clearly demonstrates that patenting can now address the 'factural' dimension of materials, acknowledging their functional usefulness (matters of fact) but also their moral dangerousness (matters of concern), and thus propose a more acceptable solution (matters of care as possible action). It does so by stating that previously irrelevant moral considerations can be transformed into utilitarian concerns, as the patent genre demands. However, it should also be remembered that this is just one patent among hundreds of similar documents that still rely on the narrowest myopic approach of patent writing. It thus remains to be seen whether the factural concern for sustainable products can spread in the patent literature.

Conclusion

My project was to investigate how matters of fact (plastics) and matters of concern/care (disposability and sustainability) are embedded in patents despite (and within) patent law and genre. To this end, I conducted a comprehensive textometric analysis of the presence of plastic materials and plastic-related concerns in mask patents.

I first recalled that patent writing is highly constrained by specific laws and rules. Patent law excludes moral considerations from patent writing; similarly, the patent institution requires patents to be novel, useful, and non-obvious, and thus leads them to insist on their generic functional character and to remain vague and open as to what specific materials can be employed to fulfill their usefulness objective. In this respect, the patent law and the patent institution can be described as another system involved in the production of strategic (McGoey, 2012) or organized ignorance (Knudsen et al., 2023).

Despite these constraints however, the empirical analysis of our corpus of 615 facemask patents shows how material and cultural considerations have nevertheless circulated in patents. The use of certain rhetorical devices, such as "preferably" and "or any other suitable material(s)," helps to mention specific materials while preserving the genericity of patents; in addition, the reference to market-based components contributes to the externalization of environmental and health considerations. However, more recently, the reference to external pressures for sustainability, or the transformation of the concept of sustainability into a material property, has helped to turn ethical concerns into caring actions and useful facts.

As the empirical material shows, this evolution is slow. The proliferation of plastics in the patent literature clearly preceded and outweighed the late and modest rise of concern and care for the body and the planet. Moreover, the statistical decline of plastics at the patent level does not imply their decline at the industrial level: on the one hand, patents tend to allude less to materials like plastics that are considered obvious, standard solutions; on the other hand, patents leave manufacturers free to use whatever materials they wish.

Nevertheless, and hopefully, despite the patent institution and despite industrial routines, patents prove to be slowly and modestly permeable to societal concerns, especially when such concerns can be transformed into functional goals and health care for both human and non-human entities. In this respect, patents can become *factural*: they can combine factual and cultural dimensions. The extent to which cultural values will take precedence over factual dimensions remains to be seen. Whether the contamination of concerns will reduce the contamination of plastics will depend on social pressure and on the ability of engineers and other actors to channel that pressure into useful inventions. At the very least, we now know that the patent literature's imperviousness to concerns is not as absolute as the patent law and institution make it out to be, and that some patent writers know how to cross the boundaries that surround their practice and care for our world at large.

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Notes

1. The full dataset is available here: https://doi.org/10.34847/nkl.51fd3r6s (accessed 1.7.2024).
2. Abbreviation for "personal protective equipment."
3. I used the query: "([word="any"] [ ] {0,2} [word="suitable"] [enlemma="material"]) within s," which returns all matches of sentences (within s) that contain the words "any" and "suitable" separated by 0 to 2 words, and followed by the lemma "material" (that returns the singular and plural forms of this word).
4. http://iramuteq.org/documentation/fichiers/IRaMuTeQ%20Tutorial%20translated%20to%20English_17.03.2016.pdf (accessed 1.7.2024).
5. Technically speaking, the analysis focuses not exactly on words but on forms, i.e. the underlying lemmas behind each particular word related to it (a lemma is the common heading behind the related words, for instance, "be" is the lemma of been, being, are, were; similarly, plastic is the lemma of plastic and plastics, etc.
6. The examples listed below are the most representative words for each class, listed in the order of their Chi-square value (link to the class). In the word clouds, the font size is proportional to this value. In our presentation, we refer to the words with the highest Chi-square.
7. https://www.britannica.com/science/plastic (accessed 1.7.2024).
8. https://www.loveyourclothes.org.uk/guides/fabric-focus-synthetic-fabrics (accessed 1.2.2024).
9. https://en.wikipedia.org/wiki/Natural_fiber (accessed 1.7.2024).
10. Patents with higher rates may be observed, with a maximum of 19.3‰ for US20060266364A1.

The Fields of Interdisciplinarity: How do Practices of Place Transform Forest Science and European Forests?

Evan Fisher

GEODE, UMR 5602 CNRS, Université de Toulouse Jean-Jaurès, Toulouse, France.

Ruppert Vimal

GEODE, UMR 5602 CNRS, Université de Toulouse Jean-Jaurès, Toulouse, France/ruppert.vimal@univ-tlse2.fr

Abstract

This paper provides an empirical account of the problem of interdisciplinarity in the field sciences, considering it as a driver of ontological change. Our case study is an ongoing interdisciplinary research project in environmental science. Its objective is to trace the long-term histories of European old-growth forests. To account for the mechanisms involved when researchers seek to do interdisciplinary science in the field, we describe 1/ four research practices that take advantage of the spatial order of the study site in order to make forests temporal processes knowable, thereby producing a field site crisscrossed by multiple spatiotemporal orders; 2/ those practices geared towards articulating these spatiotemporal orders and the limits faced by the consortium towards their complete integration; 3/ how such articulation transforms the conception of old-growth forests as spaces shaped by historical processes integrating human activities and valued ecological processes. We argue that interdisciplinary research practice in environmental field sciences does not lead to a synthesis of pre-existing domains of knowledge production. Rather, it does tend to transform both the object of study and the disciplines involved. The field, as both an object of study and a research place, becomes a broker toward ontological changes.

Introduction

Anthropocene research studies typically focus on 'real-life experiments' (Krohn and Weyer, 1994) and often encompass two major dimensions. They are based on fieldwork, which contrast with lab science by the importance granted to place specific features (Kohler, 2002b), and they seek interdisciplinarity by combining concepts, theories and methods from different disciplines (Campbell, 2005; Mascia et al., 2003).

By doing so, these studies aim to track the complex entanglements between human activities and natural processes and accordingly to provide recommendations regarding which nature to preserve and how. In this manuscript, we relate the story of one research project which focused on European old-growth forests. Our point is to ask how interdisciplinary research practice in the field affects scientific understanding and definitions of a shared object of study.

Covering less than three percent of the European forest and often perceived as primary or pristine, old-growth forests convey the iconic imaginary of the so called 'wilderness' (Barredo et al., 2021). To date however, the way past and present human activities impact such forests and the degree of naturalness needed to designate them as 'old-growth' remain unclear (Larrieu et al., 2023). Combining disciplines as diverse as history, archaeology, genetics, sociology, ecology, or paleoecology, and with a strong emphasis on ecological history, the project we followed aimed to relate the long-term histories of European old-growth forests to their current biodiversity state. What happened in their past that produced their current, exceptional state?

Representatives of each discipline recognized the limits of their own methods and often spoke about the 'complementarity' of their approaches. Many also acknowledged they had no clear vision on how to achieve this complementarity in practice. A major problem they faced was the integration of their disparate research operations into a coherent research protocol, with a view to identifying the principles and causes underpinning temporal processes in forests. Indeed, central to the study of 'old-growth forests' in Europe is the issue of their temporality. The plural pasts that environmental sciences uncover through their heterogeneous methods are precisely what produce old forests, making them what they are and answering the normative question of what forests should be (Fisher et al., 2024).

As suggested by MacLeod et al. (2019), over the last decades, a substantial body of literature has produced diverse perspectives on what interdisciplinarity should encompass and how to classify its various forms. This work has primarily focused on theoretical approaches to conceptualizing and understanding interdisciplinarity and it is only recently that empirical approaches, particularly in the field of Science and Technology Studies, have received more attention (e.g., Borie et al., 2021; Fitzgerald and Callard, 2015; Lundershausen, 2018). Given that interdisciplinarity is meant to address 'real-world' challenges, there has been a significant emphasis on assessing its outcomes, discussing what constitutes interdisciplinary success and gaining insight into the mechanisms at play (Holmes et al., 2018). In this perspective, scholars increasingly stressed the need to engage with the epistemological and ontological 'tensions' constitutive of interdisciplinary collaborations (Krueger and Alba, 2022). Rather than viewing interdisciplinarity solely as a means to solve problems, they suggest it as a broker for reshaping the very conception of the problem itself. A pioneering contribution in this regard is the work of Barry et al., (2008) and what they termed a 'logic of ontology' in interdisciplinary research.

A logic is a set of rationales about the purposes of interdisciplinarity and about how interdisciplinarity should be guided and justified. A logic of ontology is "an orientation towards effecting ontological change" (Barry et al., 2008: 25). This orientation manifests itself in particular in its intention to re-conceptualize the object(s) of research and the problem these objects pose to research. Barry et al. (2008) demonstrate that interdisciplinary research practice often does not merely result in integrating previously existing knowledge production practices. It thoroughly transforms how a shared object is conceptualized and renews the kinds of problems this object poses.

Other studies have analyzed the processes involved in creating interdisciplinarity, outlining the circumstances in which diverse disciplines, with distinct methods, concepts, objects, theories, come to interact and generate new epistemological and ontological perspectives. Overall, they acknowledged that "interdisciplinarity is both a social and epistemic process that is contingent on the context, spaces and actors involved" (Honeybun-Arnolda, 2023: 415). So far however, little has been said regarding how interdisciplinarity relates to field sciences. Yet, the field as a site for the production of scientific knowledge touches on specific epistemic issues that have received increasing attention (Ezequiel and Martín Valdez, 2021).

First among these specificities is the particular role played by place. Where the lab is often understood to suppress the specificities of place, aiming at "placeless knowledge", field sciences function by taking advantage of the spatial characteristics of their field sites, as they are found, to produce robust knowledge. Field scientists "proceed not by eliminating placiness, but by embracing it" (Kohler, 2002b: 191). Through what Kohler calls 'practices of place' in his study of 20th century field biology, field scientists seek out "patches of simplified nature", enabling them to "measure exactly, perform quasi-experiments, and read the record of natural processes as if they were experiments, inferring their principles and causes" (Kohler, 2002b: 204-205). Furthermore, as Gieryn (2006) has shown, the field is both *found,* taken as a 'natural' site, providing direct access to reality, and *made,* put into grids, objectified, quantified, using surveys and statistics, making control possible. This dual nature of the field means that not only do field scientists take advantage of the field as found, but also actively re-order and re-constitute the field through their research practices. While feeling, seeing, and understanding their study sites, field scientists shape the world they study.

This manuscript aims to analyze how fieldwork and interdisciplinarity combine when dealing with environmental issues. How are different disciplinary boundaries shaped and transformed by field characteristics, and how does this elicit new epistemological and ontological perspectives? In this respect, two theoretical contexts, mobilized in both field science and interdisciplinarity studies, have particularly captured our attention. On the one hand, the concept of 'boundary work' – which considers the constructed and flexible nature of disciplinary boundaries (Gieryn, 1983) – was used to describe the circulation of ideas, instruments, concepts, objects among different disciplines (MacMynowski, 2007) as well as between the field and the lab (Kohler, 2002a). On the other hand, the metaphor of the 'trading zone' in which different stakeholders collaborate (Galison, 1999), helped understand how researchers with distinct disciplinary approaches (Honeybun-Arnolda, 2023) – but as well scientific space and inhabited place (Kelly, 2012) – actually coexist and are dynamically transformed.

Building on these approaches, this paper provides an empirical account of how interdisciplinary field science re-arranges, redefines and reconceptualizes what is meant by old-growth forests. We particularly focus our attention on how scientists involved in the project relate spatial characteristics of forests to stories of their past and thus produce what we call spatiotemporal orders. Our argument is based on the description of two sets of interrelated practices of places (Kohler, 2002b). First, those practices related to the project's various research operations that help uncover the forest's multiple spatial and temporal orders. Second, those articulatory practices developed and contributed to getting the multiple spaces and times involved to hang together. Part of the dynamic of interdisciplinarity lies in the tension between maintaining research operations' integrity, each with its own spatial requirements, while developing practices that enable them to hang together. The interdisciplinary field embodies a multiplicity, crisscrossed by several distinct but related spatiotemporal orders, which are never fully integrated. We show that these practices interaction in the field reshapes the scientific perspectives on the forests studied and the disciplines involved. We argue that the rationale for interdisciplinarity in European forest science lies not so much in the synthesis of disciplinary knowledge as in reworking the scientific conceptions of the object of analysis.

An interdisciplinary team to study European old-growth forests

The case study retained to develop these points are two interrelated research projects, which, for the most part, include the same team members, field sites, and methods. When we, the authors of this manuscript, arrived in the lab hosting these projects, the first one had just ended. It was a two-year exploratory project (2017-2018) supported by a research public institution in France, with funds earmarked for interdisciplinary projects. It federated a disparate group of geographers, ecologists, archaeologists, and historians, around a shared object, namely old mountain forests composed of beech and fir, and a common goal, namely retracing the long-term trajectories of old-growth forests in Romania. The goal was to reach a better understanding of the part played by human activity in their history and their state of conservation. Researchers conducted an exploratory mission in areas known to the Romanian forest agency and the WWF, examining a series of forest sites that presented a high degree of 'maturity'. They selected four sites in adjacent valleys of the Maramures region with seemingly different management histories as their field sites.

This first project was presented to us as a 'test bed' for a larger project that followed. The latter initially received a four-year funding from the French Research National Agency (2019-2023), which we have been invited to take part in. We will refer to this project as the OFPP project, standing for Old Forests' Past and Present. This project focused on 8 field sites, each covering an area ranging from 45 hectares to several hundreds. Three were located in the central French Pyrenees and five in the northern Romanian Carpathians. The justification for selecting these particular sites was the forests' 'maturity', i.e., the "stage of natural development of a forest [...] evidenced by specific attributes: many large or old living trees, high volume of coarse woody debris in different decomposition states and many types of tree microhabitats on living trees" (Cateau et al., 2015: 59). Moreover, while these sites presented characteristics that were often valued and seen as requiring conservation, what made them interesting for this project is that they also presented traces of past anthropization. As Johanna, an archaeologist and the main investigator (PI) on the project (every name has been anonymized) explained:

> We currently tend to consider that it is the absence of human activity that produced mature, natural forests. However, every time we take a long-term look at their history, we find mining activity, pastoralism, and forest exploitation. Our objective is to see how human activities have participated in producing mature forests.

This objective was thus clearly identified at the beginning of the project and this is precisely what justified the diversity of disciplines invited to participate. Jerome – an ecologist who played a pivotal role in the study design – put it this way: "the interdisciplinarity specific to the OFPP project aimed to 'requalify' the concept of old forest by reworking the boundary between "natural" and "managed" forests."

The project federated 25 researchers, 2 PhD students and 8 technicians across 10 different research laboratories including five in France, one in Check Republic, one in Spain and three in Romania. The consortium was structured around two main tasks. The first focused on the long-term histories of forests while the second analyzed their recent and current bio-cultural diversity. Each task implemented several research operations, according to the various skills of the researchers involved (Table 1). An extra task (both the authors of this manuscript were in charge of) aimed at studying the consortium's interdisciplinary efforts and to build on its experience to question the relation between science and policy making.

People, materials and methods

As mentioned earlier, both this manuscript authors joined the teams after the first exploratory project had ended. R.V is a geographer interested in both the spatial relationship between humans and non-humans, and the way science and technique study it. When he was hired as a permanent researcher in late 2018, her new colleague, Johanna, directly proposed him to be part of the consortium and to coordinate the extra task of the upcoming project. Once the OFPP project was funded, E.F, this paper's initial author – and a young researcher with a background in Science and Technology Studies – was appointed on a two-year contract as a post-doctoral researcher in charge of supporting R.V.

This implied that the research for this article was both funded by the OFPP project and took the OFPP project as its case study. Our offices were set up in the lab that hosted the OFPP project. It is important to point out that, despite our participation in the research project during the research stages this manuscript relies on, we kept a position as observers. Accordingly, our implication within the team, including our participation to field missions, was dedicated to better grab the aspects of the project that structured this paper, but never to interfere with them.

The survey itself was based on participant observation, semi-structured interviews, and document analysis. Participant observation, which extended over the first 18 months of E.F's contract, focused on coordinating meetings, forest scientists fieldwork and lab work. An approximately one-month intensive observation was spent with

Table 1. Overview of the research operations involved on the OFPP project across its two main tasks. "1-ha plots" refers to the 40 one-hectare plots delimitated across the 8 study sites (3 sites in France, 5 in Romania) to conduct part of the research operations.

Research operation	Support for data collection	Sample materials	Task concerned
Pedo-anthracology	pits on 1 ha plots	Charcoal remains in soil for analysis of past forest cover and fire events	Task 1: Long term histories
Paleo-entomology	pits on 1 ha plots	Insect remains in soil as proxy for past environment	
Archaeo-anthracology	Charcoal kilns on 1 ha plots	Charcoal remains in soil for analysis of past charcoal production and forest management	
Palynology	lakes or bogs adjacent to study sites	Pollen in sediment cores for analysis of past vegetation cover	
Geochemical analysis	lakes or bogs adjacent to study sites	Sediment cores for stratigraphic analysis of heavy metal and other pollutants	
LiDAR	2-3 plots at a time on 1 site in the Pyrenees and 1 site in the Carpathians	Digital terrain model of the micro-relief of the forest floor; digital model of the structure of forest stand	
Environmental DNA - fungus	Sampling grid on 1 ha plots	DNA remains of fungus in composite soil samples for analysis of species diversity	Task 2: Recent and current bio-cultural diversity
Environmental DNA - insects	Trees on 1 ha plots	DNA remains of insects in sawdust samples for analysis of species diversity	
XRF analysis	1 ha plots	Soil samples for analysis of recent heavy metal pollutants	
Tea Bag Index	1 ha plots	Index of decomposition rates of organic material left in topsoil over several months	
Index of Biodiversity Potential	1 ha plots	Observation of Tree Related Micro-habitats (TreMs) and other ecological descriptors of forest stand	
Ecological description of forest stand	1 ha plots	Volume of dead wood as descriptor of stand structure	
Dendrochronology	3 fir and 3 beech individual trees on 1 ha plots	Wood cores for analysis of the forest trajectories over the last several hundred years	
Dendro-archaeology	Traditional wood structures in vicinity of study sites	Wood cores for analysis of wood provenance and forest economy	
History	Public and private archives	Documents relating to forests, their management, ownership, and regulation	
Sociology	Communities living adjacent to study sites	Interviews on practices and representations related to forests	

teams in the forests field, while three weeks were dedicated to observe teams at the bench in the lab. This paper's materials come from the copious notes taken during, and immediately after, these observation sessions. These observations were completed with a series of 11 semi-structured interviews with the scientists working on the project. The interviews focus was a history and schematic description of the research design, accounts of implementing research design in practice, and the work necessary to coordinate this diverse group of scientists' activities. These interviews also served as a retrospective study of the initial exploratory project (2017-2018) and as 'test bed' for OFPP. Both data collection and analysis tended to focus on a subset of disciplines that took on a central role in the project. This 'central role' manifested itself either in the managerial and scientific responsibilities taken on by discipline representatives or the importance of the discipline in the overall study design. The documents collected included research projects submitted to obtain funding for the project, sampling protocols, scientific articles written by consortium members, emails between consortium members, notes from coordination meetings, presentation supports by consortium members, scientific reports related to the study sites, and documents from outside organizations (WWF Romania, French National Forest Office, Natura 2000) that described the study sites.

During the analysis stage of our materials, we were particularly interested in how the specificities of the field sciences, *i.e* practices of place, found and made, related to the challenges and justifications for interdisciplinarity. The analysis was based, first, on organizing materials into a series of corpuses, or bodies of text that could be read as a relatively coherent unit. We thus organized our materials by research operations (cf. Table 1), with particular focus on charcoal sampling for the needs of pedo-anthracology, wood coring for dendrochronology, sediment sampling for palynology, data collection for an Index of Biodiversity Potential, and sampling for studying mushrooms environmental DNA. Although non exhaustive, these research operations provided a relevant and complementary material to build our argument. A separate corpus was established for practices related to the articulation of disciplines in the field. We then conducted thematic coding of these corpuses with a view to accounting for the role of place, both in the challenge of articulating the disciplines and in the hope of transforming scientific understandings of old-growth forests.

Practices of place in interdisciplinary field science

The following section is organized in three parts. First, we describe several practices that set up the field in such a way as to turn place into an actor in the production of disciplinary knowledge on mature forests temporality. Second, we examine those practices of place meant to articulate each research operation field. By examining the limits of these articulatory practices, we show that articulation is always partial, never definitive or complete. Third, we show that field research in practice was rationalized through the ontological transformation of the object of analysis. Namely, interdisciplinary fieldwork led project researchers to reconceptualize as well as redefine old-growth forests in Europe, and to rework the common distinction between 'natural forests' and 'managed forests'.

Producing multiple spatiotemporal orders

In the field, pedoanthracologists, *i.e.* scientists studying Holocene paleoenvironments, are interested in the charcoal remains found in the soil. They dig a pit down to bedrock, clean its vertical surface and place plastic yellow markers on the borders between soil horizons, that is, layers of soil that can be distinguished by their structure and composition. They take pictures of it and inspect each horizon carefully. They smell the dirt, take it in the palm of their hand, and rub it between their fingers. They scribble down descriptions of these horizons, paying particular attention to what led them to differentiate each of them. Finally, they take soil samples. Several kilos of soil from each horizon are placed in plastic bags, which they then label with plot number and soil horizon. These samples are taken back to the lab, where they are dried and sifted. This enables them to isolate the charcoal fragments remaining in the soil. These charcoal fragments are examined under a microscope to determine their genus or species and then sent to an outside lab to be dated. We have seen them do this several times, standing around a hole in the ground discussing the structure and composition of the soil, examining the structure of the charred wood under a microscope. When we asked them about the history of the field site, they told us stories about the site's vegetation within a several hundred-meter radius at different time periods over the last 10000 years.

Palynologists are also keen on telling stories about vegetation cover over thousands of years. However, in contrast with pedoanthracologists, they were unable to inscribe their research operations inside the 1-ha plots selected for the study. Palynology is the study of plant pollen and spores trapped and conserved in the environment, and it requires intact sediment from lakes or bogs. None of the plots presented such features. For both the French and Romanian sites, they found lakes or bogs relatively close to the selected study sites. In the Pyrenees, they started by attempting to sample sediment from the Burat Lake, situated several hundred meters above the nearest plot. To take samples, Olivier takes a clear plastic tube from his backpack, to which he attaches a series of aluminum poles. After using a bathymeter to map the bottom of what is hardly larger than a duck pond, he climbs onto an inflatable dinghy and wades out to the deepest point. This area looks flat and smooth on the bathymeter map, which suggests the sediment may be intact. He pushes the corer to the bottom of the lake, doing his best to keep it perpendicular to the sediment, and presses it into the mud. Now, all that remains in the tube as he pulls it out is just a measure of brown water. No good. He tries again and again, before concluding that the sediment has been disturbed, hence making sampling impossible. Another palynologist comments on the site topology, points to the steep slope running up from the edge of the lake, and explains that sliding debris has probably disturbed and covered the sediment. They then try sampling the bog adjacent to the lake, returning to the site a few months later with several hundred kilos of material flown to the site in a helicopter. This time, it takes the weight and effort of two full-grown adults to press a one-meter-long corer into the thick, wet bog. They then carefully remove the corer from the peat and place it in a plastic shell designed to protect it. When we asked palynologists about the past of their study sites, they would tell us stories about vegetation cover and the type of milieu dating back to several thousand years ago. These stories were not specific to a given local site, but concerned a region of up to 50 km[2].

For dendrochronologists working on these 1-ha plots, the past of the forest had nothing to do with the species composition of the site thousands of years ago. Dendrochronology is the science aiming to date events such as environmental changes, using patterns in trees annual growth rings. When Océane, a forest ecologist, carefully pulls out the tree corer from an old, twisted beech, she looks at it and says, "that's a really nice series of rings". Here, tree-rings make it possible to read the forest past. Cores are taken back to the lab and studied under a binocular microscope. Each ring's width is measured to the thousandth of a centimeter precision. These measures are fed into proprietary software, which allows them to cross reference several core samples rings and reconstruct a 'reference chronology' for each site. Tree rings "register" the "signal" or "signature" of forest events. This allows dendrochronologists to identify changes in tree growth rates for given years or periods. Events that affect the state of affairs of the entire forest are inscribed in individual trees life histories. By collating and cross-dating trees' individual life histories, and by comparing them with the known meteorological conditions in the areas at hand, dendrochronologists can tell the story, not only of individual trees or plots, but of several hundred-hectares study sites over hundreds of years.

While the dendrochronologists take coring samples from beech and fir on the plots, a forest ecologist on the team counts the number of Tree-Related Microhabitats (TreMs) on the plots with the help of an archeologist and a historian. Johanna stands in the center of the circular plot, and Jérôme, the forest ecologist and engineer who developed this research operation, walks out to the edge along a 56-meter radius, before coming back to the center on an adjacent radius, eventually covering the surface of the entire 1-ha plot. Along the way, he stops at the base of each 'habitat tree', and yells "one habitat tree"! Johanna yells back, "One habitat tree!" and scribbles it down on her clipboard. Then Jérôme yells the type of TreM on the habitat tree and Johanna repeats this back and scribbles it down on her clipboard. The forest is filled with the echoing "tree snag", "cavity", and "exudate". Jérôme explains that a TreM is "a morphological feature present on a tree" that is "used by sometimes highly-specialized species during at least part of their life-cycle". The point of counting TreMs is to calculate the Index of Biodiversity Potential (IBP), which Jérôme tells me is a "descriptive" tool that is both "crude" and "refined". The IBP provides a "refined" description of tree morphology and stand structure, translating a state of matter that exists in the present. Each morphological feature is a micro-habitat and indicates the forest's *potential* to host biodiversity, but the IBP does not account for species presence or richness. In this sense, the IBP can be said to be 'crude'. The IBP provides a description of an *actual* state of affairs in the forest taken as a proxy for a *potential* state of affairs, a potential biodiversity. Jérôme calls this the "hosting capacity" of the forest stand.

Our empirical description illustrates how the different research operations involved in the project rely on a set of practices that take advantage of the spatial organization of the field site to access forest temporalities. These practices shape different spatiotemporal orders.

Pedoanthracology relies on the specific characteristics of charcoal remains in the soil. Charcoal is immutable and immobile; it does not move and it does not change. Carbon dating of charcoal remaining in the soil provides low resolution temporal data, with a margin of error that can be up to several hundred years. However, since charcoal is relatively immobile, the charcoal location is said to be the place where the tree grew. This means that with the location of the charcoal, a radiocarbon date, and species determination, pedoanthracologists can reconstruct the milieu within a few hundred meters of where the charcoal was found, at a given date in the past, based on the species ecological requirements and phytosociology (the group of plants commonly associated with the tree).

Palynology, as Clothilde told me during an interview, requires a "history in place". Every year, pollen is released into the air by plants and ends up floating on the surface of the water. In the lake, the pollen is mixed up and homogenized before settling on the bottom. If the sediment is undisturbed by water currents, sliding terrain, or human activities, then it accumulates, slowly, over thousands of years, in chronological order. That is, sediment is organized *stratigraphically*, unlike the soil horizons that pedoanthracologists so carefully describe, which relies instead on carbon dating charcoal fragments. This stratigraphy means palynologists can construct a 'depth-age model', "that is, depending on the depth, you get the sediment age". This is what Clothilde means by a "history in place". While pedoanthracologists can successfully study the past of the forest even if the soil has been displaced, palynologists require sediment to remain undisturbed. Hence, palynologists seek out those places where sediment stratigraphy is intact.

Dendrochronology relies on what Océane calls the 'sensitivity' of trees to site conditions, climate variations, and changes in the structure of the forest stand. By 'sensitivity', Océane means that tree ring sizes vary with these changes. Some trees do not register any changes; light, humidity, and soil conditions are so favorable that their growth does not vary from one year to the next. Other trees are so constrained by their site conditions that they do not grow at all during one given year. This is especially true of beech trees. Therefore, Océane selects trees for coring that are 'dominant' – their crown reaches the canopy, warranting they receive sufficient sunlight from year to year to sustain growth – but also 'constrained', i.e., growing on a large rock, covered in lichen, stunted or twisted, etc., so that even small forest events register directly in the wood. Importantly, the form of the tree itself is organized chronologically; rings are arranged according to the order in which they grew, in a timeline that is linear and unidirectional. An event – be it drought, disturbance, release, change in climate conditions – occurs in the forest and is inscribed, in an orderly manner, directly in the spatial form of the tree.

The IBP relies on the spatial organization of the field site – the 'refined' description of stand and tree structure; plot boundaries make it possible to calculate an index. This spatiality is related both to the forest's temporality and mode of existence. Calculating the IBP relies on a set of past 'abiotic and biotic events': "a falling rock could injure the bark, lightning could strike a tree and crack the wood open, or a woodpecker could dig a breeding cavity in the trunk", which 'created' the TreMs. These past events are logically necessary for the TreMs to exist, and their accumulation indicates that the forest is 'mature'. Meanwhile, ecologists are primarily interestd in them through their current subsistence in the structure of the stand and trees. They make two inferences: from both TreMs' present to the past events that cause them; and from the TreMs' subsistence in the present to the field site's 'hosting capacity', its 'biodiversity potential'. However, this biodiversity actuality is undetermined. There may or may not be high levels of species, genetic, and ecosystem diversity. In addition to temporality, we are dealing with modality, or the way biodiversity exists. The IBP turns into an actor in its study design in order to account for the site's *potential*.

Articulating multiplicity

Now that we have described how these practices of place produce multiple spatiotemporal orders, let us examine the practices meant to articulate them. As shall be seen, each of these practices ensures only a partial articulation of the disciplines involved in the project.

The first articulatory practice of place is site selection. During interviews and fieldwork, we asked consortium members how they selected study sites, and they insisted the selection of study sites was central to study design. As one of the palynologists explained, regarding her discipline in particular:

> Your initial question about the selection of sites is crucial, and it really depends on the research question (...) So you see, depending on the question, we won't have the same way of selecting sites. This rule of thumb applies to everything, even to you, when doing your interviews: If you always interview the same person, it just won't do.

This suggests that research design is deductive: a research question and a hypothesis are formulated; sites are selected according to whether it is possible to test the hypothesis and answer the research question. And yet, site selection also depends on *exploration*, central to the 2018 first field mission in Romania, which does not square with the deductive study design. This is how an ecologist working on the project presents this first 'exploratory mission':

> We went out prospecting. We ended up in (this village) almost by chance, because there was a boarding house there that seemed nice. Johanna had a map that showed there were mines in the valley, but we didn't know what we would find, nor whether we would find forests matching what we wanted to study. (...) We didn't know anything about the site. We ended up finding a map of the old forests (in the area), produced by WWF. But we got the map only after we arrived. The boarding house owner gave it to us. One day, he came in with a little pamphlet, saying, "look, the green outline is where the UNESCO forests are". So, we looked at it and said, "yeah, look, old-growth forests". So, we went there and visited all the forests on the map. (Jérôme)

Exploration entails ranging over unknown terrain and surveying what exists there. It is impossible to know ahead of time what will be found and whether what will be found corresponds to the type of study that can be conducted. From the start, the overall project sets out to study *mature* forests long-term history. As such, a major requirement was that the sites they selected contained mature forests. It was understood that all the different specialty consortium members could contribute to answering the assemblage of research problems related to recounting forests' long-term history. The team working in the fields of ecology, mycology, and entomology would fill out their understanding of the present state of the forest through localized studies based in these forest sites. The archaeologists, historians, historical ecologists and paleoecologists would account for the forests' pasts and for the role humans had played in their development.

Selecting sites according to a research question several disciplines can contribute to is, at least in theory, a powerful practice of place for articulating the different spatiotemporal orders produced through heterogeneous research operations. It presents however, a major limit, related to precedence given to ecological considerations (*i.e.,* forests maturity) in site selection. The historian working on the project explained that, since study sites were selected according to ecological criteria and not according to archival documents availability, he was faced with a dearth of materials. If he wanted to conduct a historical study of old-growth forests, he would begin by *exploring* relevant archives, find a location he had 'a nice corpus' for, and then sought out mature forest sites that overlapped with his historical documents. Similar difficulties could be identified for dendro-archaeology, which takes wood cores from the structure of buildings (pastoral huts, churches, cabins…) and uses the tools of dendrochronology to analyze forest management practice, the forest economy, and the provenance of wood. Since exploration was conducted primarily in forests and sites selected according to ecological criteria, it was exceedingly difficult to find structures whose dendro-archaeological study could contribute to the overall project.

A second practice of place, developed early on during the project, was to inscribe as many of the research operations as possible inside shared 1-ha plots. In each study site, five 1-hectare plots were delimitated. This was understood to be a robust method of articulating the different research operations implied in the project. Whenever possible, each research operation would work inside a set of shared 1-ha plots selected from within the larger study sites. Five plots were placed semi-randomly (*i.e.,* placed randomly along a trail inside the site, in order to ensure accessibility) in each of the eight study sites. This is how Jérôme presented the reasons for inscribing as many research operations as possible inside these 1-ha plots:

> The point of the project, which I defended from the beginning, and which was later accepted by everyone, is to circumscribe all the protocols of each discipline, well, most of them actually, within a 1-hectare circle. And within this hectare, we have a description of the stand. So, fungus, dendrochronology, charcoal survey, dead wood survey, density, etc., everything is inside a 1-hectare plot, because, with the IBP, we have an environmental description of the plot. Afterwards, obviously, palynology, sociology, etc., were disconnected, outside the plot. And I can't do the IBP in a peat bog. But everything that's based on sampling, (...) it is more judicious to put them all on the same plot, where we have an environmental description. And then, if we find variations in fungi, etc., we can see whether it is correlated with variations in the quantity of dead wood, for example. With IBP, dead wood, dendrometry, everything I do, we have a description of the sample environment, whatever the type of sample. (Jérôme)

Jérôme claims the articulation of these different research operations is based on the ability to relate their findings to an external environment. This is possible because this environment has been constituted and described with the tools of ecology, notably through the IBP survey. The spatial articulation of these practices of place relies, in part, on turning one of the heterogeneous fields – i.e., the field of forest ecology, which provides a description of stand structure, dendrometry, and quantifies deadwood, which serves to verify that the sites under study are indeed mature forests – into an *environment*, that is, a state of matter which surrounds and contains the other field sites. It is this environment of *mature forests* that the other research operations must explain.

A limit to this practice of place is that several research operations on the project required such specific sites that they could not be made to fit on the selected plots. The team labeled them 'off plot approaches'. The environmental historians working on the project require archives to talk about local forest history. To be able to talk about the provenance of wood, the person doing archaeological dendrochronology requires pastoral huts and old churches from which to sample wood cores. The project sociologist requires local community members to conduct interviews about traditional forest management practice. Palynologists require lake or peat bogs for sediment sampling.

The third practice of place oriented towards articulation is scaling. An important working hypothesis of the project was that the history of a changing 'milieu' and of past management practice could be related to the current 'environment' (species composition, biodiversity hosting capacity, stand structure, dead wood volume…). For such meaningful differences to show up in their results, researchers need to find the right *scale* at which they can make the different disciplines relate to each other. That is, while many of the research operations took their samples from the 1-ha plots, it was not necessarily at plot scale that such differences would appear in the analysis. Nor could they assume that meaningful differences would appear at field site scale.

For instance, two of the Romanian field sites were selected precisely because one presented visible and invisible effects of human exploitation (signs of recent logging, heavy metal pollutants from an adjacent mining site) while the other did not. Yet, the preliminary results from this study, published in 2020 in *Quaderni Historici* (Py et al., 2020), suggest that the anthropized 'managed forest' does not present "any significant difference in structure, composition and litter decomposition" when compared to 'unmanaged' old-growth forest (Py et al., 2020: 389). According to an entomologist working on the project, the problem was finding the proper scale at which to observe trends:

> Are anthropized forests [in the study] less rich than old-growth forests? Not so at plot scale. However, when you cumulate the data, they are. That's where scale is interesting. (...) Locally, we don't see any change. But if you stop there, you're not looking at the right scale! For us, what emerges in the results is that there actually is a valley effect.

Passage between scales is achieved differently for each of the research operations and usually depends on the sampling strategy. Mycologists and entomologists interested in the genetic diversity of insects and mushrooms test the robustness of their sampling protocol by calculating an 'accumulated species richness curve', a kind of marginal analysis of the benefits of taking more samples. The curve visually represents the number of new species per additional sample. If the curve starts to plateau at the top, it means that even if they continued accumulating new samples, the number of new species would not increase significantly. This sampling protocol allows passage between scales by 'duplicating local measures' and through 'accumulation'. According to the entomologist working on eDNA:

> You could wonder whether the sampling is robust enough and, to be honest, it probably isn't. But sampling is how you go from one scale to another. There is what we call the local scale, the 1-hectare plot. Then the landscape scale, when you add up all your 1-hectare plots. And finally, the intermediate scale, which is the site, or stand. That is a management unit, i.e. the unit a forestry treatment is applied to, and at which management choices are made. And some things happen at this scale, that don't at other scales, and that you are not going to see by just averaging for data. It's cumulative.

The limit to scaling up is that not all the research operations involved in the project were designed to scale. The measure for biodiversity hosting capacity, the IBP, is a case in point.

> For simplicity's sake, our index is limited to the forest stand, disconnected from the landscape scale. Which we know is a mistake! Indeed, if you want to reason in terms of biodiversity, obviously you have to reason in terms of the landscape. You have to change scales, to look at how fragmented and isolated your forests are. But I don't look at the scale when I quantify the stand hosting capacity. My biodiversity hosting capacity is what it is in a given place. (Jérôme)

Jérôme explained that the reason scale is so important to biodiversity is because small patches can host high levels of species diversity, but, because of how isolated these fragments are, the species in question have low genetic diversity and have insufficient access to diverse habitats. This poses a serious threat to the species' continued capacity to maintain a healthy and stable population in future. While those who developed the IBP are aware of the necessity to situate biodiversity at 'landscape' scale, they developed their protocol to help foresters and forest engineers maintain managed forests with a sufficient number of TreMs. The goal was not to produce landscape level analyses, and, within the framework of the project, it is difficult to scale.

Transforming European Forests

Taken together, the articulatory practices of site selection, shared plots, and scaling represent the overall spatial organization of the study design. This study design, based on a series of eight field sites, each covering only a few hundred hectares, and forty 1-ha plots, and integrating both 'on plot' and 'off plot' sampling strategies, is meant to produce historical knowledge at high spatial and temporal resolution at a very local level. However, the multiple spatiotemporal orders produced by these heterogeneous practices of place are never completely integrated. Instead, as we shall now see, the novel entanglement of these spatiotemporal orders produced a transformed object of analysis. That is, old-growth forests became something else through these interdisciplinary associations.

According to our notes, this is how Johanna, the PI, related the study design to the research objective during the June 2021 fieldwork in France:

> We selected sites deemed to have characteristics that should be conserved and protected: a high degree of naturalness, maturity and age, often associated with old-growth forests. The objective of the overall project is to look in detail at what in their past, what in their history could produce this present state that we value? Indeed, we currently tend to consider that it is the absence of humans which produced these forests. However, everywhere we looked, we found clues of mines, charcoal-kiln terraces and pastoralism. The objective is then to see how human activities have participated in producing these spaces. (Johanna)

This ensemble of partially-articulated spatiotemporal orders transformed how forest scientists conceptualized the place of human activity in old-growth forests. This transformation was precisely what justified their interdisciplinary efforts. The originality of the project, and the rationale for interdisciplinarity, was to integrate human activity into the historical processes that produced mature forests' present, valued ecological state, where most approaches tend to see human activity as necessarily harmful. This was at the heart of the project objectives, as one forest ecologist explained during an interview:

> What is interesting about this multidisciplinary, interdisciplinary approach, whatever you call it, is the objective of requalifying these forests. [...] What we want to emphasize is that natural forests, mature forests are the result of past anthropization. Granted, they have not been exploited for three or four hundred years, but they co-evolved with humans and humans had an important place in these forests. Humans didn't wipe out everything. They had management methods that were reasonable and well-suited to the forest. In fact, what we really want to question is the dichotomy, common in forest science, between "natural forests" and "managed forests". And that's what multidisciplinarity makes possible. (Océane)

However, it is important to say that the ontological changes as described here were not only framed *a priori*, declared as truth within the project objectives. They concretely occurred thanks to the study design. Shared outings into the field were essential to effecting this transformation. During an interview, the PI for the project, who had previously worked primarily in managed forests, explained she was 'shocked' when she first visited a mature forest. As an archeologist and the daughter of a saw-mill owner, Johanna explained:

> I used to think that a nice forest is a high forest. And a clean one, too. Yes, a clean forest, so no dead wood on the ground. A forest with dead wood everywhere is a forest that is not well-managed. It's a forest that's dying. And so, I changed my… I don't know what you'd call it, there was a "paradigm shift", if you will. And I discovered this is what a forest, a natural forest, in quotation marks, looks like. But paradoxically, what was also fascinating was that there were traces of management in these forests too, especially in Baiut, there were traces of recent management. (Johanna)

On the other hand, the ecologists on the team, accustomed to working in Old-Growth Forests, did not necessarily notice these traces. Johanna gave the example of a team of ecologists that visited one field site on their own. Their initial field report claimed that the site presented no visible signs of past human activity and concluded that the forest was pristine and natural. However, when an interdisciplinary team visited the same site, they found dozens of tree stumps on the 1-ha plot, which was clear evidence the forest had been exploited less than 50 years prior. The PI explains:

> So, we realized that the fact of going into the field all together was very enriching. Indeed, everyone observed different things. And that can open you up to seeing new things. I liked that a lot. It frees

> your eyes to notice things that you don't observe, wouldn't observe otherwise, because you become monomaniac when you always work from your own discipline. (Johanna)

So, shared outings into the field effected a 'paradigm shift' for an archaeologist who tended to see heavily managed, "clean" forests as healthy, and she taught the ecologists used to working in mature forests how to pay greater attention to traces of past management.

These changes had an important impact on how the ecologists and historians working on the project problematized and defined their object of study. During an interview, one ecologist explained to me that, after working with the historian on the project, he now sees the historically changing property regimes in place as an essential component in explaining how old-growth forests attained their current maturity levels. Who owned the forest and what ownership allowed them to do can account for the forest's ecological characteristics. Conversely, the historian working on the project told me that he "can no longer see [him]self working on forests without the ecologists' outlook." This was because working with ecologists "changed [his] vision and understanding of forests. [He] previously didn't use to see forests as autonomous ecosystems." And this historian added:

> Knowledge and interdisciplinarity are created in the field. By observing others' disciplines, by participating to sampling, I was able to understand the purposes, the methods, and how to bring things together.

In short, where the articulation of the plural spatiotemporal orders produced in the field was always partial and incomplete, the project did manage to effect a significant change in how the scientists involved understood and problematized their object.

Conclusion

By taking up the challenges faced by project members as they attempt to describe old-growth forests collectively, this paper provides an empirical account of the specificities of the field as a place where environmental sciences can become interdisciplinary.

We locate the purpose of interdisciplinarity in 'a logic of ontology', that is, a rationale that justifies interdisciplinarity through its orientation towards effecting ontological change in the research objects and relations (Barry et al., 2008). As such, we identified how interdisciplinarity in the field, by combining multiple practices of place, transformed both how scientists interact and what old-growth forests are.

As a starting point, we showed how the practices of place of each discipline involved in the project contribute to shaping their own boundaries by enacting not only place but also time differently. Each discipline took advantage of the spatial characteristics of the field – the structure of a forest stand, the relative immobility of charcoal trapped in the soil, the form taken by a growing tree, the history in place of lake sediment, the microrelief of the fossilized forest floor…, – to access a series of heterogeneous temporal processes. Thus, they effectively produced multiple spatiotemporal orders.

We further showed that the main interest of this interdisciplinarity project lied in its ability to transform the field as a trading zone between the different disciplines involved, a zone where different practices of place have been incited to communicate, where people, tools and ideas could circulate, where new conceptions of the study object could emerge. Through the project interdisciplinary design, several practices were developed with a view to articulating the plural spatiotemporal orders. Each presented significant limits, and the complete alignment of all disciplines never occurred. Our account insisted on, and drew out, the tensions between making room for each discipline and finding a way to relate across the distance that separated them. In the field, each discipline distributed agency unequally. Each practice of place constituted the field site as a different kind of actor, with different kinds of behavior, even when project members were understood to be working in the 'same' field. This means that, even in a shared study site, each discipline conserved its 'truth spots' (Gieryn, 2006), understood here as specific spatial properties of the field from where, or about which, certain knowledge claims can be made. In the field, forest places and times remain plural, hanging together in partial connection and partial contradiction.

However, whatever the hybridization of the various research operations implemented in the project, the members of the consortium came to see the field as being crisscrossed with several spatiotemporal orders and this transformed their understanding of mature forests. Such transformation was achieved by recounting the long-term history of mature forests in Europe, in order to question the idea that their current and valued ecological state was the result of an absence of human activity. It was possible precisely because they shared a common project in which each ecological and historical approach conceded compromises in favor of the overall project goal of requalifying old-growth forests.

Importantly, the transformation of their object of study occurred not only conceptually, but registered too in how the project's scientists perceived forests. Indeed, shared periods of fieldwork, with representatives of different disciplines participating in all research operations, led members of several disciplines to transform their experience of the forest while being in each other's workspaces (Hadfield-Hill et al., 2020). As these researchers questioned the distinction between 'natural' and 'mature' forests and learned to perceive the forest differently, an important shift occurred in what counted as a research problem. Instead of looking at simply whether or not there had been human activity in forests in order to adjudicate on its 'pristine' state, they sought to account for those human activities that could be compatible with the continued existence of mature forests.

By describing the transformations operated in field sites as both study objects and research places, we questioned the common understanding of interdisciplinarity as an effort to synthesize or integrate previously existing entities or domains of knowledge production (Fitzgerald and Callard, 2015). Rather than relying on a stable state or a result, we showed that interdisciplinarity in the field hinges upon a risky dynamic of becoming, between making a place for the disciplines to maintain the repertoire of practices that can ensure the production of robust knowledge, and finding a way to align and articulate the spatiotemporal orders they find and make in the field. Although their articulation will remain forever incomplete, the encounter in the field between research operations transforms the object of study, the problems it poses, the disciplines involved and scientists' perceptions.

While doing science can be considered as a specific way of interacting with the environment (Ingold, 2021; Latour, 2004), our account shows how interdisciplinarity, as a framework to embrace the full complexity of the Human/Nature relationship in the Anthropocene, involves transformations deeply imbricated with the field specific characteristics. The field becomes an opportunity, a broker between different disciplines and an active agent toward ontological changes.

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McIntyre Lee (2022) How to Talk to a Science Denier. Conversations with Flat Earthers, Climate Deniers, and Others Who Defy Reason. Cambridge: MIT Press. 280 pages. ISBN: 9780262545051

Laida Arbizu Aguirre
laida.arbizu@ehu.eus

Lee McIntyre's *How to Talk to a Science Denier* comes out at a time of growing international concern regarding the diminishing faith in scientific organizations. The COVID-19 pandemic, intense debates over climate change, and the rise of conspiracy theories have turned science denial into a significant obstacle for democratic societies. From the perspective of his expertise as a philosopher of science, McIntyre argues that science denial is a complex issue with substantial philosophical consequences, reaching beyond social and political discussions. Acknowledging the significant dangers that denialism presents to scientific advancement and the integrity of democratic systems, McIntyre asserts that it is crucial not only to challenge science denial but also to actively engage in efforts aimed at lessening its impact. He contends that these initiatives should focus on fostering trust, showcasing intellectual humility, and encouraging clear and effective communication regarding scientific methods and standards.

At the core of McIntyre's thesis lies the assertion that science denial is not merely a consequence of irrationality or informational deficits but is fundamentally rooted in the framework of identity-protective cognition. Drawing on his own unsuccessful attempts to persuade Flat Earthers through the presentation of empirical evidence, he concludes that "facts alone are not enough to change minds that are motivated by something deeper" (p. 29). Instead, McIntyre situates science denial within a broader context of motivated reasoning, ideological entrenchment, and distrust of scientific authority, aligning his perspective with a substantial body of social science research that demonstrates the limited efficacy of fact-based interventions in the presence of strong identity commitments and affective polarization (Braman et. al., 2010; Kahan, 2017).

One of the most distinctive and philosophically significant aspects of McIntyre's approach is his sustained emphasis on empathy and respectful engagement as foundational strategies for addressing science denial. Rather than advocating for confrontational or derisive tactics, McIntyre insists that "respect, trust, warmth, engagement […] are the common threads that run through such first-person accounts" (p. xv). He is explicitly critical of approaches that rely on ridicule, confrontation, or displays of intellectual superiority, contending that such strategies tend to reinforce defensive attitudes and further entrench epistemic divides. Drawing on both empirical research and his own field experiences, McIntyre argues that building trust through patient, empathetic dialogue is essential for overcoming the deep-seated distrust that often underlies science denial. This commitment to engagement and mutual respect not only distinguishes McIntyre's intervention from more traditional, information-centric models of science communication, but also aligns with contemporary scholarship that emphasizes the relational and affective dimensions of effective public engagement with science.

The book offers a nuanced array of case studies that illuminate both the diversity and complexity inherent in science denial. While public discourse often associates science denial with specific political orientations, McIntyre is careful to demonstrate that the phenomenon transcends partisan boundaries. In particular, he devotes significant attention to skepticism regarding genetically modified organisms (GMOs), critically examining whether this form of skepticism can be classified as a type of science denial more commonly attributed to liberal ideological perspectives (p. 122). Through detailed accounts of his discussions with friends who express anti-GMO views, McIntyre explores the discomfort and cognitive dissonance that emerge when deeply held beliefs are challenged (pp. 124–130). These episodes underscore the importance of adopting an empathetic and patient approach when engaging individuals across the ideological spectrum.

McIntyre's work makes a significant contribution by establishing a dual-axis framework for engaging with science deniers. The first axis concerns communication style. Drawing on science communication theory, McIntyre advocates for dialogic and interactive engagement as opposed to the traditional one-way, monologic dissemination of information. This approach acknowledges that effective science communication involves not only imparting knowledge but also fostering genuine dialogues that recognize and address the audience's values, beliefs, and cognitive biases. The second axis involves the strategy of rebuttal. McIntyre differentiates between content-based and technique-based rebuttals, both of which he suggests are most effective when delivered with empathy and within authentic conversational exchanges (p. 152). This model is grounded in philosophical and psychological research on reasoning and attitude change (Lewandowsky and Oberauer, 2016) and empirical studies on mutual learning in science communication (Schmid and Betsch, 2019). By synthesizing these insights, McIntyre offers a framework that bridges normative theory and practical strategies for real-world science communication.

While McIntyre's focus on interpersonal strategies is a notable strength, it also limits the scope of *How to Talk to a Science Denier*. The book centers on practical, one-on-one engagement as a vital tool against science denial in everyday contexts, yet it pays comparatively little attention to broader structural and institutional factors—such as media dynamics, political polarization, and organized disinformation—that sustain denialism. McIntyre recognizes these broader issues (p. 178) but does not delve into them extensively in this book, though he does explore them more thoroughly in other publications such as *The Scientific Attitude* (2019) and *On Disinformation* (2023). Readers interested in a thorough examination of structural factors may find this book somewhat limited. For wider insights into how disinformation campaigns and broader (media) environments bolster denialist trends, Naomi Oreskes and Erik M. Conway's *Merchants of Doubt* (2010) and Maya J. Goldenberg's *Vaccine Hesitancy: Public Trust, Expertise, and the War on Science* (2021) offer valuable supplementary perspectives.

A further area for consideration involves the scalability and generalizability of McIntyre's methodology beyond immediate interpersonal contexts. While McIntyre recognizes potential difficulties in translating empathetic dialogue and technique rebuttal to digital platforms, he does not thoroughly examine the degree to which these methods can be effectively adapted for online environments, where communication dynamics differ significantly. Specifically, the increased anonymity, rapid information spread, and significant polarization typical of many online spaces may compromise the trust-building and subtle conversational interactions that McIntyre deems crucial for overcoming science denial (p. 182). These considerations underscore the practical limitations of McIntyre's framework and highlight the need for considering how relational and rhetorical strategies might be adapted or supplemented to address the distinctive challenges of digital communication environments. As recent scholarship demonstrates, the unique affordances of online platforms can amplify misinformation and hinder the development of productive dialogue (Lewandowsky et al., 2017; Vraga and Bode, 2020).

The author's longstanding engagement with the subject matter is evident in the depth and sophistication with which the topic is addressed throughout the work. *How to Talk to a Science*

Denier is a lucid, accessible, and philosophically rigorous exploration of one of the most urgent challenges of our time. McIntyre combines personal narrative, empirical research, and philosophical analysis to offer a practical and ethical framework for engaging with science deniers. Notably, McIntyre's emphasis on empathetic, practice-oriented engagement with science deniers resonates with STS discussions about the role of the researcher as a 'diplomat'—someone who navigates contested knowledge spaces and fosters dialogue across epistemic divides. This approach aligns with STS's longstanding interest in the social processes through which trust, credibility, and expertise are negotiated in public controversies. Although the book's emphasis on micro-level interactions leaves certain macro-level issues insufficiently addressed, its dual-axis model provides substantial insights into bridging discursive divides and fostering epistemic resilience within contemporary information environments. For this reason, the volume is highly recommended for scholars and practitioners in STS, philosophy of science, and science communication, as well as for general readers seeking to comprehend and confront the challenges posed by science denial in the present era.

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Ask Kristine and Søraa Roger A. (2024) Digitalization and Social Change: A Guide in Critical Thinking. London, New York: Routledge. 304 pages. ISBN: 9781003289555

Sophia Leipert
leipert@em.uni-frankfurt.de

Kristine Ask and Roger A. Søraa's *Digitalization and Social Change: A Guide to Critical Thinking* offers a comprehensive exploration of the complex interactions between digital technologies and social change from a critical perspective. The authors provide a framework for understanding how digitalization is (re)shaping various aspects of daily life. They aim to not merely present "quick facts" about digitalization, but rather to develop the "necessary cognitive tools" to evaluate the digital technologies woven into the social fabric (p. 5). By doing so, the book intends to empower readers to reflect on the consequences of digitalization, critically analyze its foundational premises, and question the notion of its inevitable effects. In this, it is aimed primarily at students via providing theoretical and methodological tools for understanding and analyzing these sociotechnical interplays. For years, the authors observed, their students requested such a book that would offer a comprehensive guide to digitalization and social change (p. xi).

The book is structured into four parts. The first part introduces a critical perspective on digitalization, which is conceptualized as a sociotechnical process that encompasses social and technological transformations associated with the development, implementation, and/or utilization of digital technology. The second part delineates theoretical frameworks that aid in identifying, comprehending, and analyzing the interactions between technology and social change. The third part presents empirical case studies that demonstrate the ramifications of digitalization across five domains – health, work, control, culture, and identity – highlighting its multifaceted nature and the complex consequences it engenders. The final part then synthesizes the book's content, underscoring the insights gained from empirical analyses of digitalization processes in relation to the primary themes of social change, user perspectives, and critical thinking. In addition, the final part offers guidance for future applications and provides analytical and methodological resources.

Overall, the authors advocate for a sociotechnical perspective to digitalization, emphasizing the importance of nuanced views regarding the potential and limitations of technology – both positive *and* negative (p. 17). This perspective is introduced in the book through stylized key STS theories such as Interpretative Flexibility (p. 46f), which posits that technology can be interpreted in various ways and has differing consequences depending on the context, and Delegation (p. 47), which involves analyzing the interactions between humans and technologies as an exchange of responsibilities and tasks. Additionally, Actor-Network Theory (ANT) (p. 48) conceptualizes technologies as components of networks that include both human and non-human actors, and Domestication Theory elucidates how technologies undergo a 'taming process' to become usable, necessitating interpretation and negotiation between technology and the user (p. 67). Finally, Script Theory examines how values are materialized and conveyed through design, seeking to understand how technologies communicate preferences and worldviews through their functionality and aesthetics (p. 84).

In addition to examining digitalization, the book critically analyzes and operationalizes the concept of social change. The authors use the somewhat ambiguous term to describe and justify the book's focus (p. 272), referring to global 'rapid change' more comprehensively co-produced by digitalization. As part of this, they advocate for examining the diverse and unequal experiences and consequences associated with the change (p. 271). This is pertinent: technologies build upon one another, and while social change is fundamental, it is also incremental. With the concept of social change being as broad as digitalization, the authors primarily aim to empathize with the relationships between these concepts, processes, and ongoing transformations. The book's critical aim should thus not be interpreted as a guide to achieving a normative vision of an alternative, specific future. Instead, criticality is engaged through how and why-questions, and with the concept of 'it could be otherwise,' following Latour and Woolgar (1979) and Star (1988). This positioning reminds us to contextualize the deployment of technologies: how they are formed as objects of thought and action, as well as designed in practices that entail also politics. The imagination of how technology could be otherwise especially enables us to question normality in its procedurality and constructed character, rather than accepting it as granted (pp. 98–110). While not a novel idea to experienced STS scholars, this provides a valuable framework for future scholars, which indeed makes sense in the context that the book's primary target audience is students.

The authors' roles as Associate Professors of STS at the Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology (NTNU) in Trondheim, may have influenced the book's emphasis on Norwegian case studies. This emphasis emerged from translating the original Norwegian-language edition, seeking to address their primary audience of students while providing an overview of STS research in Northern Europe over the past decade. While these cases offer valuable insights into digitalization within the (Northern) European context, they may not resonate as strongly with readers seeking for more globally diverse perspectives. Given the book's aim to provide a broad introduction to digitalization and social change, a greater inclusion of case studies from different cultural and political contexts would have strengthened its applicability.

The book nevertheless serves as a valuable resource for educational purposes, offering guidance on the development and enhancement of critical thinking skills. The perpetuation of STS traditions aids in understanding knowledge processes and technology as co-produced by cultural and social phenomena, making them more accessible for critical analysis. The inclusion of examples from popular culture and science fiction elucidates these entanglements in the book, while the empirical cases underscore the practical study of digitalization. The authors furthermore appear to adopt a didactic approach through the inclusion of 'activity boxes,' which prompt interaction and critical engagement with the discussed issues, potentially rendering information more tangible, memorable, and accessible. As demonstrated by Deslauriers et al. (2019), such (inter)active teaching methodologies enhance learning outcomes, deep engagement, and critical thinking more effectively than students' preferred but less effective linear teaching methods.

Drawing from personal teaching experience, the book is recommendable not only for STS students, but any students enrolled in non-STS programs that explore digitalization. Its interdisciplinary approach makes it particularly useful for students and scholars in cultural sciences, urban studies, human geography, and related fields. The book may also be of significant value in disciplines that traditionally place less emphasis on qualitative methods or on courses outside the social sciences. Although the book may appear somewhat repetitive to advanced researchers, it functions effectively as a comprehensive refresher on established concepts within STS too. The book's clear and consistent structure supports this, offering introductions and summaries for each chapter, along with two concise 'cheat sheets.' The analytical cheat sheet encapsulates the five principal theoretical concepts of the book and relates them to analytical practice. The methodological cheat sheet offers guidance on data collection, specifically designed to aid students in writing about digitalization, and here integrating established research methods such as interviews, observations, and document analysis.

In summary, *Digitalization and Social Change: A Guide in Critical Thinking* is a well-structured introduction to the study of digitalization and its societal dynamics. While its focus on Norwegian case studies and some of its repetitiveness may limit its applicability, the book provides a strong theoretical foundation and encourages critical and practical engagement with digitalization processes. The sociotechnical approach highlights the mutual shaping of technology and society, highlighting the reciprocal relationship between users and digitalization. By focusing on this co-production, the book situates these processes in the interplay between social and technical elements, making it relevant for those responsible for, affected by, and capable of effecting changes. The key conclusion of the book, and perhaps that of critical research addressing technology in general, is to advocate for broad political discussions of social problems and their complex dynamics, rather than relying on simplistic (technological) solutions as something through which they might be fixed. The book's strengths lie in this commitment to critical inquiry. It achieves this by encouraging a meticulous and critical examination of the implementation, design, and usage of technologies, cognizant of the inseparable nature of social and technical factors in shaping digitalization processes.

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