Materializing values

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Abstract
In contrast to the history of science and to science and technology studies, the value discourse in the philosophy of science has not provided a thorough analysis of the material culture of science. Instruments in science have a special characteristic, namely that they explicitly and clearly emerge from and remain embedded in social contexts, and are thus imbued with values. We argue that the materials (in most cases they are artifacts) used in science are necessarily influenced by both epistemic and non-epistemic considerations. A consequence of this is that a descriptive term cannot give sufficient information whether an artifact is performing in an acceptable way. Instead of the prevailing descriptive approach, we therefore advocate a normative notion of values in the material culture of science. To this end, we connect the material culture of science to the so-called "new demarcation problem", in order to lay the foundations for a value-sensitive approach to the analysis of instruments. By assessing the five approaches of demarcation concerning value-influences, it will be shown that they break down at various points if the material aspects of science are taken seriously.

1. Introduction

While the material aspect of science has long been recognized in the history of science and in science and technology studies (STS), the value discourse in the philosophy of science has not provided a thorough analysis of the material culture of science. Instruments in science have a special characteristic, namely that they explicitly and clearly emerge from and remain embedded in social contexts, and are thus imbued with values. We therefore argue that the materials (in most cases they are artifacts) used in science are necessarily influenced by both epistemic and non-epistemic values. A consequence of this is that a descriptive term cannot give sufficient information whether an artifact is performing in an acceptable way. Instead of the prevailing descriptive approach, we therefore advocate a normative notion of values in the material culture of science. To this end, we connect the material culture of science to the so-called "new demarcation problem" (defined in the next paragraph), in order to lay the foundations for a value-sensitive approach to the analysis of instruments.

The new demarcation problem was introduced recently by Bennett Holman and Torsten Wilholt (2022) to point out the need to distinguish between legitimate and non-legitimate value-influences within science. “[T]hat some values must, at times”, they write, “play some role, does not entail that anything goes. There remain clear cases of biased science that cross a line between the inevitable management of epistemic risk in the light of value judgements and an inadmissible distortion of inquiry” (2022, 211). While Holman and Wilholt focus on scientific ideas, concepts, and theories, we call attention to the material side of science, as we believe that it complicates things even further. We attempt to show that all five approaches to demarcation identified by Holman and Wilholt based on the literature break down if the material aspects of science are taken seriously. The new demarcation problem calls for more attention to be paid towards the material side of science.

The paper proceeds as follows: in Section 2, we introduce the topic of values, and how they are typically represented in the contemporary philosophy of science discourse (2.1); we also identify a general fear, or rather a refusal, to engage with materials in the literature (2.2). In Section 3, we discuss some of the major issues surrounding material culture, why such a discussion can offer new insights into the nature of science and scientific inquiry, and how it would be more than a useful extension of and supplement to the traditional theory-oriented philosophy of science discourse (3.1). In this section, we also present our arguments for a unique feature of materials in science, namely that they necessarily instantiate both epistemic and non-epistemic considerations of values (3.2), with numerous examples to substantiate our claims (3.3). Lastly, in Section 4, we debate the new demarcation problem and argue that it misses important points of the sciences and the values that were introduced to them through material artefacts.

2. From values to materials and back: pictures of science

2.1. Values in philosophy of science

During the twentieth century, many philosophers and scientists thought that science is or ought to be *value-free*. While almost everyone agrees that science is driven in part by specific epistemic values, like truth-seeking, consistency, predictability, explanatory power, systematicity, etc., the value-free ideal (VFI) comes down to a more specific idea:

> The value-free ideal of science is best described as an ideal that is based around the claim that social, ethical, and political values should have no influence over the reasoning of scientists, and that scientists should proceed in their work with as little concern as possible for such values. (Douglas 2009, 1)

Many scholars now argue that such values *do* play an essential role in science. All those who accept that *certain* seemingly non-epistemic, or moral/political etc. values enter science at different levels subscribe to the so-called value-laden ideal (VLI) of science.

To make sense of the debate in the first place, people tend to differentiate between epistemic and non-epistemic values within science. The first of these categories refers to those values that are internal to the concerns of scientific activity and are supposed to guide scientists towards the truth or a chosen epistemic goal, like attainment of knowledge. As Davis Baird (1999, 1) notes, epistemic values are those that concern realities that “come ahead of moral, political, or ideological values.” Non-epistemic values, on the other hand, are things that are supposedly external to the scientific enterprise and stem from more subjective sources. The values of democracy, equality, morality, freedom, religion, and public health are usually deemed to be important in our social life, but *should be* kept outside of science so as not to distract us from the straightforward quest for *truth* and *knowledge*.

Despite their legitimate and significant role, it is not clear at all which epistemic values are *genuinely* epistemic. Questions often arise, and have still not been settled consensually, whether epistemic and non-epistemic values can be divided *clare et distincte.* Though there are minimal standards (like truth being epistemic, morality being non-epistemic), many values (like systematicity, equality, consistency, and especially simplicity and objectivity, etc.) could be given epistemic and non-epistemic interpretations alike. Broadly speaking, epistemic values are indicative of truth or knowledge, and in this paper, we stick to this basic notion and always make explicit what values we take to be epistemic or non-epistemic within each example (mainly for heuristic purposes and not to settle often age-old disputes).

Various positions have been advanced on the normative-descriptive axis of the debate as well: Non-epistemic values often *do* play a role, but they *should not*; or non-epistemic values *do* play a role, and that role is *essential and ineliminable*. In fact, a significant portion of the literature defending VLI has sought to show that non-epistemic values regularly play an important role in scientific practice, such as existential safety in vaccine design, social background assumptions in data selection, profit motives in research, political and economic views when setting standards, and *that* role is also essential and ineliminable.

This list of entrance points clearly shows the general approach of *philosophers of science* as it developed in the twentieth century. This approach generally focuses on theories, theses, arguments, data, interpretation, and hypotheses, with the addition of theoretical issues and some general institutional matters, such as funding and the social stratification of scientists based on geography and gender. It is no surprise that philosophy of science tends to focus on theory and the logical-cognitive connections between different parts of knowledge production. Consequently, it makes sense that the issue of the presence of values in science is addressed through theory.

2.2. Fear of all things material

In 2012, Alan Richardson announced a new “empirical history of philosophy of science,” calling attention to hitherto less discussed and analyzed forms and conditions of knowledge production and discipline-shaping. Richardson encourages historians and philosophers to focus on institutions, publication venues like journals and edited volumes, and places, instead of individuals and arguments. He argues that

> We have … very little idea of how to think about other aspects of the philosophical landscape—we generally ignore institutions, centers, departments (despite our current mania for ranking them), research organizations, learned societies, professional groups, and so forth when thinking about the history of philosophy in the nineteenth and twentieth centuries. (Richardson, 2012, 3)

This “empirical history” project of analyzing, reconstructing, understanding, and evaluating such information and institutional issues is *empirical* in the sense that it focuses on worldly affairs instead of abstract, individual, and intellectual achievements.

We can draw an interesting parallel here. Besides such empirical matters as institutional conditions, publication venues, and textbooks, scientific work depends on material things as well, and in many ways. One might point, for instance, to observation, calculation, measurement, and experiments, all of which rely heavily on human-made material objects. Therefore, scientific artifacts are *necessary and ineliminable* conditions of the production of knowledge about the world. You can discuss the results of scientific procedure as purely cognitive-epistemic products, but you cannot practice science without all the material and artifactual equipment and tools. Because of this intertwined relation between artifacts and science, objects are very often not just neutral facilitators of knowledge, but play a much more complicated, robust epistemic role in producing scientific knowledge.

Given their essential role, one might wonder why material and designed artifacts have played such a *minor* role for such a *long time* in the philosophy of science. Material culture and the practical aspect of science (re-)emerged in the 1970s and then went mainstream in science and technology studies, the philosophy of technology, and design studies, before finally also eliciting the interest of philosophers and historians of science. Nonetheless, many philosophers have followed the development of the field with skepticism and fear. Susan Leigh Star explains this phenomenon by noting how non-epistemic issues could penetrate into scientific practice:

> In some ways modern science can be seen as the push to erase individual, craft skill from the scientific workplace, to ensure that no idiosyncratic local, tacit, or personal knowledge leaks into the product. Anyone should be able to reproduce scientific results if they can afford the equipment and follow the recipe. Research findings that are purely personal or irreplicable are just not science. (Star 1992, 275)

It is often emphasized, especially by adherents of VFI, that science is a universal, objective, and international cognitive business; thus, any subjective, contingent, and local concerns that would bias the results and hinder the process ought to be reduced and eventually replaced by more standardized procedures (very often by algorithmic, mechanical, or quantitative processes). Theories, concepts, and arguments seem to perform much better on that account, especially if they are framed in an international language, English in particular, or modern symbolic logic, like first-order predicate logic.

It is mainly due to sociologists, notably Harry Collins, that the community has come to see that the defects of the replication of experiments lie at the very heart of science. Collins (1985) has argued, after many years of fieldwork among physicists, that there is a built-in replication problem, which is based on *tacit knowledge* and individual *skills*. Despite all the theoretical instructions for how to build equipment and design experimental scenarios—for example, in instruction texts and operational handbooks—the decision on the validity of the experiment leads to the so-called "experimenter's regress." The correctness of the outcome of an experiment depends on the quality of the experimental apparatus, while in turn only a correct experimental apparatus is able to give correct outcomes, hence the regress. To correctly set up an experiment and its instruments, many things need to be adjusted, and these steps and skills cannot be learned from papers and guides—some things can only be learned and done together with other experts via common socialization and practices (cf. Collins and Kusch 1998).

This shows quite clearly that in dealing with experiments, observations, measurements, and calculations, all the previously suppressed individual, subjective, tacit, skill-based, material, designed, and artifactual parts of the scientific process resurface from time to time, so that certain values inevitably do enter the discussion—but such values often have a bad reputation because of their too worldly and empirical character. They are there, of course, but they should not influence scholars.

To deal with such contingencies and other matters that might divert attention and focus away from the mighty enterprise of theoretical knowledge, science and the reflection on science have undergone radical changes. Already decades ago, Star has argued that

> [a]s modern science was developing its industrialized form at the turn of the century, the problem was to contain the craft side of science while elaborating the formal, abstract parts in a way that would feed the new modes of work and organization. Part of this did involve an overall shift from science as cultivated gentility to science as white-coated technique. *It is the delegitimation, not the disappearance, of craft skill and individuality that is important here*, and it is a part of several contexts: professionalizing, industrializing, commodifying. (Star 1992, 276, emphasis added)

In other words, the hope was that by shifting attention away from the material side of science, it would simply disappear from the discussion. The important message of this passage that the material aspect of scientific procedures—and the craftspeople maintaining those material conditions—has not disappeared from science. It is not as if tools, equipment, lenses, containers, physical models, dishes, needles, engines, and countless other instruments have been deleted from science, but scholars (especially philosophers and scientists) simply have not regarded them as actually contributing *that much* to the sanctioned pantheon of our *theoretical knowledge*, let alone the value discourse. They never disappeared—they have just been delegitimated.[1]

Perhaps the same goes for Richardson's program: By exalting such contingent matters as the empirical conditions of knowledge production in history, philosophy of science would lose some of its epistemic security and foundations. As Paul Humphreys (2016, 8), a prominent systematic philosopher of science, has written (in a handbook aimed at surveying the field and shaping future research within it), we have already learned the lessons of historical, sociological and similar studies, and thus "contemporary philosophy of science is oriented toward the current state of the various sciences." Not surprisingly, Humphrey's edited volume of invited essays devotes only three of 42 chapters primarily to historical and social issues within science (one to ethics, one to values, and one to the social organization of science). One might sense here as much confidence in the systematic philosophy of science as fear of making it worldly and contingent simply by embracing the subjective element and the material conditions that maintain and shape the field.

This is why we would like to emphasize the material side of science; despite its immediate significance for countless scholars, it is not evident that the material aspects of theories and argumentative structures also need to be investigated within philosophy of science per se. And although the question of "values" is taking shape within the philosophy of technology,[2] and with the material culture of science getting more and more attention, the value discourse in the philosophy of science still lacks an interpretative framework for the physical instruments of science. In that sense, our approach is closely connected to

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[1] This recognition parallels what happened to values throughout the twentieth century: Historical studies have shown that starting with the early morally and socially engaged philosophy of science of logical positivism, values have played a prominent role in philosophy of science, and the scientific community only started to hide and disregard them with the political turmoil brought about by the Cold War (see Reisch 2005).

[2] See, for example, Borgmann (1995), Durbin (1972), Ferré (1996), Flanagan et al. (2008), Ihde (1990), Manders-Huits (2011), Pitt (2000), van de Poel (2015), Verbeek (2008).

Richardson's empirical program, as it concerns the material side of the value discourse, things that emerge in classrooms, laboratories, popular venues, and other educational agendas.

3. The material culture of science

There is a pressing need for a sound understanding of the role of values in instruments, given that modern scientific work is tied to technology and material culture in many ways. Experimentation, observation, measurement, and most of the other practices of scientific inquiry rely on tangible, material instruments. With the development of disciplines such as material culture studies and science and technology studies, and intellectual and rhetorical strategies like the practice turn and the material turn, the instruments of science are becoming more and more central for understanding scientific knowledge. These new strands of research have started to emphasize the material aspects of science, and within this the practical aspect of scientific inquiry.

One of the main fields in this instrument-oriented tradition in the history and philosophy of science concerns experiments, as they are most directly connected to instruments. For almost three decades, there has been a growing body of research about the role of experiments in scientific practice and theory-making.[3] Instrument-oriented discussions tend to focus on problems concerning material culture and its relation to knowledge production, while touching upon crucial issues related to science in general. These include the boundaries of science as a social institution, the problem of producing reliable knowledge, the relation between the natural world observed through instruments and theory, and the practical and theoretical issues of experimentation.

Andrew Pickering (2008, 292), for example, emphasizes that "studies of scientific practice confront us with the brute materiality of science, the omnipresence of machines and instruments in the laboratory. Science has a material culture, irreducible to either knowledge or social relations," so that "the culture of science is a hybrid of the material and the social." Star (1992, 257) also stresses the importance of the study of the material culture of science, by arguing that "the stuff of science has as much to tell us as do the ruined remains of a dead civilization. It is the embodiment of skills, arguments, selections, and deletions of scientific theories." In a similar manner, Hans-Jörg Rheinberger (2010, 22) claims that "the constitution of modern scientific thought is mediated by instruments. An epistemological break and epistemological obstacle are always related," while Baird (2003, 2004) argues that material instruments have the same importance in scientific inquiry as theories. Stressing the epistemic importance of material culture, Jutta Schickore (2016, 1) argues that researchers have "turned their attention to experimental practice because they wished to demonstrate that the study of published theories and arguments gives only an incomplete picture of investigation pathways, of the negotiation involved in producing inscriptions, and of the sites and tools of experimentation."

The problem, however, is how to actually account for the material instruments of science. Traditionally, mainstream philosophy of science has focused on theories and

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[3] For instance, see Ackermann (1985), Hacking (1983), Harré (2003), Hon (1989), Latour (1990), Pickering (1992, 1995), Radder (2012), Rheinberger (1997, 2008), Schickore (2016, 2017), Shapin and Schaffer (1985), Warner (1994), and Werrett (2019). Recently, however, some researchers have tried to show that the accepted narrative about the so-called experimental turn is more complex than thought. The history of philosophy of science has undergone more nuanced changes, suppressing certain topics not necessarily due to epistemic values and reasoning (Potters and Simons 2023).

explanations, but the methods that work for theory may not work for the study of instruments. In most cases, instruments have been treated as reflections of theory, but this method soon turned out to be insufficient. Baird (2004, 4), for instance, after describing how Michael Faraday's first electric motor helped him to communicate and prove his ideas, notes that the motor plays a much more fine-grained role than just illustrating the theory: "there is something in the device itself that is epistemologically important, something that a purely literary description misses. The epistemological products of science and technology must include such stuff, not simply words and equations." Thus, the stuff of science does more than just passively reflect certain theories and propositions, and its epistemic role has changed dramatically. As such, the passive view has become obsolete, and a more fine-grained approach has started to appear in fields such as science and technology studies and the philosophy of technology. A prominent example of this is Albert Borgmann's *device paradigm*, in which he analyzes the delicate relationship between users and technical devices, focusing on how they are consumed, used, and perceived, and what effects they have on society's fabric (Borgmann 1984). For Borgman, the relationship between technology and science is not straightforward; while "modern science lets the world appear as actual in a realm of possible worlds", modern technology "reflects a determination to act transformatively of these possibilities" (1984, 27).[4] A more recent take on the topic is by Andrew Feenberg (2017), who offers an analysis of sociotechnical rationality, focusing mostly on various economic, administrative, social, and political aspects of technosystems.

3.1. Tools, artifacts, and values

Things and theories are similar in the sense that they both exist in a particular social, historical, cultural, and scientific context, and consequently they are both entangled with values. Scientific instruments are the end results of a series of decision-making processes, and these decisions are grounded in many different factors. They are influenced by the purpose of the object,[5] shaped by its makers, the supposed audience, their knowledge, budget restrictions, and technological environment. All these factors are rooted in both epistemic and non-epistemic value-laden assumptions about science and technology. Every aspect of the making of a scientific instrument, from beginning to end, is therefore embedded in a sequence of value-laden decisions. These aspects or stages of science include the choice of what to represent; who is going to make the object; in what way the instrument will be made; what materials will be chosen; which features will be emphasized, ignored or shaped in different ways; what implicit and explicit commitments the instrument's commissioner and maker have; and whose overall decision will be favored—all of these are far from being value-free.

Take the following example of how material culture is relevant for understanding the role of values in science. A notable social consequence of material culture was the controversy of authorship. What was considered scientific and what wasn't was often decided on the basis of who designed the instrument that led to a particular discovery. If the

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[4] Defining the similarities and differences between science and technology proves to be a challenging endeavor. There is no widely agreed upon stance on this topic. For an early, but still relevant statement, see Bunge (1966), for Borgmann's analysis see his (1984, 15-31). The literature is vast and still growing, and the discussion of these is outside of the scope of the paper; here we differentiate between science and technology, and treat technical artifacts as tools for reaching scientific goals.

[5] Purpose and intention are way too complex issues even within studies of design and scientific materials, thus we can only refer to the reader to some basic considerations in the literature; on the unintended and unwanted side-effects and revenge of technology, see Tenner (1996).

tool was designed by an experimenter of lower social status, then it was more likely that no scientific credit was given to it. Thus, a non-epistemic value such as authorship is necessarily present in artifacts: An artifact may have been labeled as a mere tool if an experimenter designed it, while being lauded as a discovery if it was created by a scientist (Morus 2016, 99). The reason for this, according to Mark Thomas Young (2019, 134), is the historical difference in the evaluation between theorizers and experimenters, which started in antiquity, and “persisted through the early Middle Ages, where operative and theoretical forms of knowledge and practice were often kept separate from one another.”

In these cases, material objects acted as demarcation tools between science and mere craft. Thus, science has been enmeshed with different values that reflect the given cultural circumstances—and consequently, certain discoveries have been held in much lower esteem because of social hierarchy. Notable examples of this problem are Robert Boyle and Robert Hooke. Even though Hooke made many important scientific discoveries, such as discovering new stars and the laws of elasticity, and his published work on microscopy was of the highest quality, his accomplishments were largely underappreciated compared to ‘elite’ scientists such as Boyle—just because of his lower social status as an experimenter. In this case, social values about the hierarchy between theorizer and experimenter determined the status of a discovery, and the perceived importance of the instrument by which it was made, even though Hooke’s inventions were also led by epistemic goals.[6]

When it comes to any investigation into material things, a philosopher of science would ask: What can we learn if we focus on the possible materialization of values? Are there any original insights rooted in the study of the material culture of science that shed new light on the entanglement of epistemic and non-epistemic values in science? In Section 3.3, we will return to some of the insights offered by the study of the material culture of science. Below is a brief summary.

(i) In some cases, the history of certain materials can explain the development of research programs or a sudden change in their direction. Rheinberger cites the example of the development of protein synthesis in biochemistry, in which test tubes played an important epistemic role. Similarly, Catherine M. Jackson (2015) argues that glass and the practice of glassblowing transformed chemistry, causing a revolution in the discipline.

(ii) A close analysis of the visual properties of material models can reveal scientific insights and worldviews that might not be written down in contemporary textbooks, but are present visually. Since visual knowledge is usually passed down and replicated in later material models, an analysis focusing on materials can highlight this knowledge transfer (see the examples in Section 3.3).

(iii) Studying the practices and tools of science and their relationship to each other can reveal aspects of knowledge production that would otherwise remain hidden because they can hardly be translated into theoretical descriptions. A good example of this is Gerald Holton’s (1978) examination of Robert Millikan’s famous oil drop experiment, which was later extended by Barry Barnes, David Bloor, and John Henry (1996). A close reading of Millikan’s laboratory notebook revealed many controversial material and practical aspects of the experiment. Despite the experiment’s ostensibly straightforward nature, meticulous attention to detail was essential to ensure accurate results. This involved properly shielding the apparatus, keeping tools free of dust, and ensuring a stable voltage. Additionally, pre-

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[6] For the relevant literature, see Hacking (1983), Collins and Kusch (1998), Shapin (1989), and Shapin and Schaffer (1985).

existing beliefs and expectations, various adjustments to the experiment, the selective reporting of successful trials, and overlooking of flawed ones all contributed to the publications that ultimately earned Millikan a Nobel Prize. While some discrepancies between his results and expectations were due to faulty equipment, he also attributed errors to his apparatus in some cases when it was operating correctly. For example, Millikan's notebook occasionally mentions instances where something went awry, including both actual mishaps and potential sources of error.

3.2. The necessary entanglement of epistemic and non-epistemic values in materials

While the importance of materials in science may sound like a truism to some, artifacts are rarely considered in philosophy of science, having been set aside as uninteresting tools and technicalities.[7] Even though science and technology studies, for instance, have emphasized the political, social, and economic aspects of material culture, scientific artifacts are a special type of object that would benefit not only from a descriptive, but a *normative interpretation* of values. The design of scientific artifacts is determined by values that are prominent in engineering, such as cost, safety, and benefit; and at the same time, they are designed for a specific scientific goal or goals—such as measurement, observation, or data collection—meaning they are also determined by scientific values and principles. Hence, epistemic and non-epistemic values work *together* in scientific artifacts. This entanglement of different values in artifacts results in different proportions of distinct values. Despite philosophical attempts to do so, one cannot simply carve out epistemic values out of non-epistemic values in the operation of science in a reliable way. The consequence of this is that the presence of non-epistemic values is unavoidable, and the question becomes one about how to draw the line between the legitimate and non-legitimate balance of their presence. At this point, the examination of the material aspects of science joins Holman and Wilholt's new demarcation problem. Before we delve into the merging of the two, let us take a look at how epistemic and non-epistemic values are necessarily entangled in artifacts.

Epistemic dimension: Scientific artifacts have an epistemic dimension, as they are designed and used to reach epistemic goals, like the attainment of truth and knowledge, the dissemination of information, and applicability in educational contexts.

Non-epistemic dimension: As scientific artifacts are created by scientists, technicians, engineers, and their peers (that is, by human agents), they are shaped by human decisions and choices, as well as by determinations arising in specific social, cultural, technical, and economical contexts, and are constrained by ethical and socio-political norms.

Scientific artifacts are often different from things that are used in everyday contexts. While ordinary things can have utilitarian aims that are affected by other values, such as cost, benefit, safety, and sustainability, they do not have epistemic goals in the sense that scientific instruments do. Take, for example, the growing presence of *political artifacts* in

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[7] Previously, as already noted, historians of science regarded artifacts as *unproblematic*, and claimed that they do not initiate knowledge; nowadays, however, "historians have recognized that the role of instruments in experimental science has been much more complex" (Helden and Hankins 1994, 3), and that ideas are embodied not only theoretical venues, but in material things as well (Werrett 2019, 3).

cities. Examining the politics of material things, Robert Rosenberger (2017, xii-xiii) highlights that “a device like a park or subway bench is simply an inert object, certainly not something with a mind or intentions, and thus obviously not among the category of things we would normally call ‘guilty’ for any reason, let alone callous or cruel.” In stressing the importance of this problem, he states that “we must develop a way to understand objects like the bench as capable of participating in large-scale collective ends. It is crucial that we understand them to be things open to certain uses, closed to others, and amenable to concrete alteration” (Rosenberger 2017, xiii). Rosenberger examines the subtle ways city benches, bus stops, and other artifacts are designed specifically to prevent certain forms of behavior and to foster others. That is, everyday artifacts obtain a value dimension because of their origins, places, usages, and frequently also due to their unintended offshoots (see Tenner 1996).

Prominent and well-known examples of such value-laden artifacts are the low-hanging overpasses on Long Island, New York, discussed by Langdon Winner (1980). The architect of these peculiar bridges was Robert Moses, who, according to his biography, deliberately designed them to be far too low for buses to pass underneath. The reason for this engineering decision was to prevent buses from going to Jones Beach, a park also designed by Moses. Upper- and middle-class citizens, who usually owned a car, were thus able to travel under the low overpasses and get to Jones Beach for leisure, while “poor people and blacks, who normally used public transport, were kept off the roads because the twelve-foot-tall buses could not get through the overpasses” (Winner 1980, 124). The bridges were manipulated through a particular engineering decision to prevent certain types of behavior and foster others, thereby discriminating against poor people. The apparent political dimension of these low-hanging bridges aligns with Rosenberger’s analysis of anti-homeless benches in urban areas (Rosenberger 2017). This illustrates that certain engineering and design decisions can enhance particular social problems, control behavior, manifest authority, and act as tools for political power.

A consequence of this is that the contexts and values of creators and end users are transferred onto instruments. Material culture studies, and science and technology studies have shown quite clearly how contextual (that is, non-epistemic) values become entangled in tools and instruments. One could object, however, that tools and artifacts are created with certain objective and empirical *facts* in mind, namely how they will be used, what laws constrain their possibilities, etc. While such facts would seem to be purely epistemic in nature, determining the outcome and having nothing to do with human agency and non-epistemic concerns, the philosophy of science has shown in great detail that not even apparently pure facts are value-neutral. Baird (1999, 6) emphasizes this problem with reference to Galileo Galilei’s value-laden practice: “Galileo’s decision to investigate the heavens with the telescope was not the only investigative option open to him. He took this option for a variety of reasons, which included his need to court the Court and his pugnacious desire to show up the academics.” The materials of science, and with them the practices of science, thus *have to be* shaped and *determined* by non-epistemic values as well.

Not that it is always easy to see these non-epistemic values in action. Given that facts become consensualized, so that end users often take them to be objective, independent elements of the world, Bruno Latour and Steve Woolgar (1986) have devoted much of their energy to showing how facts are constructed in the laboratory. But instruments and materials are in a similar position. Trevor Pinch (1986), in his major sociological treatise on solar-neutrino detection, has called scientific instruments "black boxes." As many scientists simply use instruments as neutral information containers and transmitters, they rarely think about their *origins* and the *disputes* surrounding them when they were first designed. Their usage, results, and operation in normal conditions are not at all questioned; they are reliable tools. But they have a history, Pinch (1986, 214) has argued, with various *social struggles* becoming "embedded in a piece of apparatus. Black-boxed instruments are the carriers of social relations," and thus of non-epistemic values. It takes time and energy, of course, to go back in time, or to observe, in ongoing work, all the social struggles or non-epistemic values that have become black-boxed along the way.

Consequently, there is a *necessary* entanglement of the epistemic and non-epistemic values that are present in the material culture of science and shape scientific inquiry. This is a much stronger statement than simply pointing out, through concrete examples, that non-epistemic and epistemic values are to be found in science and its materials. Rather, it is a normative conceptual idea that aims to capture the *inherent* goal of science to attain knowledge, and the essential *human-made-and-shaped* character of artifacts.

3.3. Examples of value-laden scientific materials

In this section, we will go through a set of limited and carefully chosen examples of typical materials or widely accepted artifacts, which are emblematic of the situation at large. That is, using the notions from Section 3.2, each example aims to substantiate the idea that scientific instruments always have epistemic and non-epistemic features at the same time, and that their final construction is a mixture (or even *compromise*) of those different values. It would be problematic to try to determine a creator's original intentions (especially as alleged direct intentions may be false, and people may also be deceived about their own goals and intentions), making it impossible to know whether an artifact is of purely epistemic or non-epistemic design; but philosophical reconstructions can excavate conceptual issues to at least *highlight* certain epistemic or non-epistemic dimensions that overrule a given project.

While the reader will notice that we have collected quite a number of examples, with their multiplicity we aimed to represent the diversity and homogeneity found within the material aspects of science. By that, we also hint at one reason why theoretically-oriented philosophy of science is not able to grasp the actualities of science in a systematic and comprehensive manner (and thus why it needs some extra socio-empirical input). Although going through all the examples could be demanding, they all serve the same point from different angles. Behind their discussion, our "through-line" is one issue: 'is there a non-ad-hoc way to delineate legitimate and non-legitimate mixtures of values - epistemic and non-epistemic - in the operations of science when dealing with its material culture?'[8] As we will highlight it in Section 4 – by scrutinizing one of the examples – when focusing on examples from the material culture of science, the demarcation between epistemic and non-epistemic values and their legitimate and illegitimate uses seems to be unattainable. Thus, philosophy could prove to be a valuable asset in further clarifying matters connected to this issue.

Microscopes. Microscopes are certainly complicated instruments from a philosophical point of view, and today it is widely accepted that they do not function as a mere looking glass through which scientists peer to observe and analyze phenomena.

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[8] We are grateful to one of our referees for helping us to clarify this point.

Observation through a microscope is a fundamentally distinct form of vision than looking with the naked eye. Discussing epistemic issues in nineteenth-century microscopy, Schickore (2001, 131) mentions strong disagreements between scientists about what they were seeing: “Fibers were described as hollow or solid, blood globules as round, flat, or concave, and bodily tissues as composed of fibers or, alternatively, of globules.” There were multiple reasons for this dissent: different lighting, preparation and handling of the specimen, varying instrument types, levels of magnification, and equipment conditions. Thus, the observational data obtained were the products of different circumstances, material resources, costs, levels of maintenance, and several other possible factors.

On the one hand, scientists have to know something about the entity they are looking at; and on the other hand, they have to know the properties of the tool and to learn how to use it. Thus, the practice of using a microscope relies on assumptions, previous knowledge, expectations, and technical expertise. As Ian Hacking (1983, 189) puts it, one does not really see with a microscope in the ordinary sense, but by virtue of diffraction. Scientists have to learn to see through a microscope through practice, just like a scuba driver learns to see in the ocean by swimming in it. Hacking (1981, 320) describes the perceived microscopic image as a map that represents the “interactions between the specimen and the image of radiation.” Besides, before a microscope has been used properly, the observed things cannot be seen “in the detail on which the future success of the observation depends” (Rheinberger 2008, 4). Therefore, it is only after using the microscope and seeing the observed thing in detail that it will yield sufficient information.

Microscopes are built for epistemic goals, such as observing and comparing entities more precisely, getting visual information about them, and testing hypotheses. Today, for example, new types of microscopes are being developed to circumvent the problem of intervention. During traditional microscopic procedures, various tools are used to render the object of investigation visible—in the case of tissue, these are usually organic dyes or large proteins. Whether natural or artificial, these markers change the functions of live cells, or the cells need to be chemically fixed for subsequent staining. In any case, artifacts are introduced, and it is difficult to ascertain whether the image under the microscope reflects the true reality or an artifact-infused reality. During the last few decades, various techniques have been developed to reduce or eliminate this kind of artificial intervention, including stimulated Raman spectroscopy (using a few atoms as markers) and cryo-electron microscopes (freezing the subject of investigation to a cryogenic—i.e., very low—temperature to avoid chemical fixation). Beyond the obvious epistemic value of objectification (i.e., reducing the amount and degree of intervention and thus the artificial additions to the system of knowledge at hand), these new machines nevertheless exhibit and rigidify the obstructions to scientific research that are at play. Due to their costs (typically between half a million and several million euros) and complexity of maintenance, their accessibility is heavily restricted, and their usage requires good personal relationships, professional connections, hard-won negotiations, or major funding. That is, you need money or the right socio-political environment to materialize your epistemic values using these new microscopes.

Test tubes. Test tubes are iconic scientific instruments: They are among the most widely known, distributed, and used tools in science. While the test tube has gone through smaller changes and developments in recent decades, it is one of the best examples of an epistemic object in a laboratory (see further Rheinberger 1997, 2008). Their use is connected to an endless number of experiments, one of them being protein science. So much so that Patricia Clark (2019, 1175) has noted that “the history of protein science is largely the history of test tubes.” Before the nineteenth century, scholars used whatever materials were at hand for testing chemicals, including a wide range of materials, such as metal, glass, or ceramics, and sometimes even ready-made objects like domestic wine glasses (Jackson 2015). The practical, and with that the epistemic, dimension of experimentation changed radically with the invention of a heat-resistant, stemless glass vessel, namely the test tube designed by Jöns Jacob Berzelius during the 1820s, and the growing availability of glass in general. The main epistemic values of glass test tubes were the accurate observation made possible by the transparency of the material, its chemical inertness, and its small scale, which “made it possible for chemists to accomplish what complex, large-scale, expensive scientific apparatus could not” (Jackson 2015, 45). Jackson claims that glass and test tubes made from it made possible the development of modern-day chemistry. [9]

However, a non-epistemic value, namely the low production cost (in contrast to the high production cost of microscopes), also contributed to the popularity of glass test tubes, making it possible for amateurs to perform experiments as well. While previously, only wealthier practitioners tended to have access to instruments and the means to hire instrument makers, nineteenth-century developments in glassmaking and glassblowing made experimentation accessible to a wider audience. Describing the work of John Griffin, a Scottish publisher and chemist, in popularizing chemistry, Jackson (2015, 51) emphasizes the knowledge distribution aspect of glass test tubes: Griffin sought to “extend chemistry’s reach and accessibility, and, with the rise of chemical glassware and glassblowing, he took steps to popularize these essential new components of practical chemistry.”

While test tubes are tools that help us obtain new knowledge, they can also hinder it. When the famous American physician Silas Weir Mitchell experimented with various snake venoms, his research was based on a heat hypothesis, namely that during heating, the destructive power of the snake venom would decrease and eventually disappear. Mitchell reported in his laboratory protocols that “death occurred after longer and longer times, and the bird that received venom heated to 212 °F survived the injection” (Schickore 2017, 136), thereby drawing the conclusion that the hypothesis was valid. It quickly turned out, however, that he had made a mistake in the experimenting process concerning the test tube-venom interaction:

> He reminded his readers that boiling caused coagulation of a part of the venom and that the active portion of the venom was in the fluid, not in the coagulant. He had been forced to work with very small quantities of venom, which meant that the amount of fluid venom was minute. During the boiling process, most of that fluid would cling to the test tube and would thus not be injected. This was the reason why at higher temperatures death occurred more slowly or not at all. (Schickore 2017, 137)

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[9] A very typical example of the fusion of epistemic and non-epistemic values would be objectivity, which has different layers of meanings in different contexts. Objectivity usually incorporates epistemic ideals (such as certainty and freedom from biases and subjectivity) and non-epistemic ideals (avoiding politicization and moralization based on taste and personal preferences, or the contrary, being moral and fair by overcoming particular perspectives). Objectivity is, however, an enormous topic that cannot be discussed in detail here; on its complex history within science, see Daston and Galison (2007), and on its narrower context within material studies, especially within the context of chemistry, see Baird (2000).

Test tubes are epistemic agents that shape our knowledge of the world, helping us design, develop, and carry out experiments. Though they contribute to reproduction across laboratories, they can also negatively affect our epistemic situation, by biasing and distorting information; hence their standardized appearance (as an epistemic value) prevails only in certain circumstances.

Human taphonomy facilities (HTF). Taphonomy is a "part of forensic science that deals with the actions and processes that impact upon organisms from the time of their death until their discovery" (Byard 2017, 473). Understanding how bodies decompose, and how the specific environment with all its organisms and artifactual circumstances influences that process, plays an obviously significant role in forensic science, and consequently in everyday criminal investigations as well. And to understand the data at hand during an investigation, one also needs insights into the decomposition process—which requires observing bodies on a regular basis. To obtain sufficient data, scientists have established facilities where animals serve as analogs to human bodies, to study their decomposition processes in a scientifically rigorous way. These animals have included pigs, sheep, and rabbits, with the first of these in particular providing relevant and significant information.

For a while, it was assumed that animal taphonomy facilities are superior to investigations in humans: Their advantages are "mainly associated with the commonality between individuals and the possibility of replicates," given that "animal carcasses can be routinely and cheaply acquired for multiple replicate studies to ensure results are statistically valid," and that these animals have "typically common origin, diets, exercises, weights, ages and manner of death" (Williams, Rogers and Cassella 2019, 75). These continuities and recurrences are required for any *replicable scientific study*, and rely heavily on the general idea of science's *systematic character.* These are typical epistemic values, although the motivation behind animal facilities is obviously related to ethical, that is, non-epistemic concerns, since a facility with dead animals might be less shocking and possibly raise fewer questions than one with human bodies.

Nonetheless, human bodies have also been donated from time to time to academic and medical institutes, and the first HTF was established at the University of Tennessee, Knoxville in the United States in 1981. The facility is under the direction of the local medical school and occupies a wooded plot of 10,000 m^2 that is closed to laypeople. As an *artificial object*, this HTF—often called a "body farm"—is a place where scientists put various bodies in the ground for longer periods of time to let them decompose. To ensure variability in the conditions and histories of the bodies, scientists expose them to various phenomena, designed according to their investigative concerns and previous historical examples (drowned bodies, placement in the trunk of a car before burying, different types of clothing, and so on). This way, scientists have been able to create natural microclimates to *study* and *observe*. Eventually, other scientists or students (occasionally detection dogs, too) are invited to the field to search for bodies, document the excavation and study the remains. Such facilities provide invaluable experience (of sights and smells, especially), information, and data for forensic scientists and anthropologists that would be impossible to gather in such a systematic fashion otherwise. HTFs have also shown, however, that despite the replicability of pig decomposition (due to shared diets, body mass, genetics), "no amount of repeatability will account for the differences observed when compared to human decomposition" (Williams, Rogers and Cassella 2019, 76).

After these major systematic differences were confirmed, more HTFs have been established in the last two decades (eight in the U.S.A., and one each in Australia and the

Netherlands), which have provided even more information and knowledge about how diverse microclimates affect the decomposition of human bodies. These HTFs are therefore well-designed scientific objects (in a sense, counterparts to natural crime scenes and graveyards) that function as *outdoor laboratories*, motivated by and crafted based on epistemic values of experimental data gathering, educational utility, and reliability of data. Many ethical questions could be and have been raised, notably due to the gruesome character of HTFs, and thus their establishment is often blocked by ethical and even religious concerns, despite all the noted epistemic values (Williams, Rogers and Cassella 2019). HTFs are also expensive political objects that need to balance the cost against the benefits they provide to forensic science. However, some of these concerns have been mitigated by the wishes of potential body *donors*, which are being respected in line with the general principle of informed consent (taken from medicine).

Isotype charts. Otto Neurath's famous Isotype is a peculiar version of visual education that emerged in the mid-1920s as the "Vienna Method," later renamed *Isotype* (*International System of Typographic Picture Education*) to emphasize its international character (itself being a non-epistemic value). The project aimed to present as much statistical information and factual knowledge as possible to the public, educated and uneducated alike.[10] To achieve this aim, Neurath and his team of graphic artists and scientists developed a special *technique*: Instead of representing numerical changes by enlarging a given pictogram, they depicted numerical interrelations through *serial repetitions*. After developing a major set of *abstracted* symbols (always designating the same thing), with *standardized* colors (each with a definite meaning), the Isotype method focused on representing numerical data using these pictograms,[11] to dispense with detailed written information. In doing so, Neurath sought to reach the illiterate, children, the uneducated, and disabled people (Groß 2015; Körber 2023).

As material objects, Isotype charts were thus designed to be understandable for everyone. By making them colorfully engaging and entertaining, while keeping them as simple and structured as possible, Neurath wanted them to be more effective than written educational texts. He argued that verbal statements, formulated in a neutral manner, are usually "dull and unattractive," whereas "visual education can be neutral without being dull" (Neurath 1996, 253). As this neutrality was an explicit aim of the whole educational project, the Isotype charts were designed in line with specific non-epistemic values: Knowledge was to be accessible to *everyone*, especially to those in *need*, the working class, the illiterate, and the poor. Knowledge dissemination, an epistemic value in itself, was democratized, thereby exhibiting a non-epistemic value. Isotype charts served *as objects* (in fact, *scientific objects*, designed by experts following rules and applying specific skills), [12] not just to transfer knowledge, but to make it *accessible*, maximizing its potential to be disseminated and to empower the masses. Isotype charts are neutral only in the sense of

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[10] Edward R. Tufte is one of the first important contributors to the visualization of statistical data (Tufte 1983).

[11] Even though they are pictograms, the museums where Isotype charts were exhibited often also had physical models of houses and cities because of the planning processes in which Neurath became involved (and whose results he again represented through charts later on).

[12] As designed and created scientific artefacts, Isotype charts required specific sets of skills and some form of tacit knowledge, thus necessitating an inner circle of experts around Neurath, despite the explicit democratizing goals and aims of the method.

not making a claim for a specific thesis, but obviously non-neutral in the sense of fostering specific non-epistemic values.[13]

Fossils and fossil preparation. In his 2019 book, Derek Turner argues that many paleontological practices can be characterized as a form of aesthetic engagement with fossils and the landscape that contains them. As he writes,

> nearly all of [the] work on the epistemology of historical science has neglected the aesthetic dimensions of the practice of paleontology. Yet we cannot really understand the science without thinking about those aesthetic dimensions. I'll use the term paleoaesthetics to refer to the study of the aesthetic dimensions of historical science. (Turner 2019, 1)

Turner suggests that in paleoscience, the epistemic and aesthetic dimensions cannot be sharply separated. This is an important observation, as fossils may be seen as non-designed materials of science that are just "out there" to be discovered and interacted with. But even such materials embody both epistemic and non-epistemic values. Although fossils carry information and bring us closer to knowledge about the world, excavations and archeology in general nonetheless come with numerous value-laden human decisions: Which part of the soil and the material it contains should be counted as belonging to a fossil? Where to draw the boundaries? How to separate soil, dirt, fossils, bones, and other parts of a dead creature? These decisions may also turn on epistemic and non-epistemic factors.

In the context of fossil preparation, Caitlin Wylie (2021) claims that a "raw fossil" becomes data (the evidence that a research community uses to support a particular claim) largely in the course of the preparator's work. Wylie argues that fossil preparation is a creative process in which preparators, who have a different educational background and set of tacit knowledge than paleontologists, make practical, aesthetic choices that then take on epistemic significance in later stages of research.[14]

Material models. Dioramas, specimens, and taxidermy are special types of scientific tools, and in many ways, they have different epistemic qualities than images. They are three-dimensional, meaning that they can be displayed, viewers can walk around them and see their back and sides, they have a surface, they can be touched (sometimes), they may have a smell, they can be dissected (sometimes), they can be made of many different materials, they can disintegrate or be repaired with new materials, they may be painted, or they may display raw and organic materials alongside artificial ones. These tactile qualities in many ways enhance the epistemic qualities of a scientific tool.

The making of material models can be understood as a series of arrangements and decisions. Star (1992, 259) discusses in great detail the case of taxidermy. She claims that

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[13] For a contemporary discussion of the ethical dimension of visualization, see Correll (2019). It would also be interesting to think of published books as scientific objects. As the main sources of knowledge transfer, they clearly embody epistemic values; at the same time, cheap paperbacks (like the famous Penguin books) also have various constitutive non-epistemic features: their size, quality of paper, appearance, price, and most importantly, public reach.

[14] One of our reviewers has pointed out that while many instruments are designed, a significant portion of the material culture in science is about what is found, i.e., things that exist outside of the scientific enterprise, which in time could turn out to be causally relevant to our endeavors. One example would be fossils in the ground that are obviously out there, exist independently of us, and with which we simply interact. That being said, what we deem *part* of the fossil, and how we draw its *contours and borders* (what is fossil, what is dirt) is still the result of an educated guess or a scientific decision. This would suggest that all those things that simply exist and "wait" for us to interact with them are transformed into designed artifacts at the very moment of interaction.

the practice of taxidermy is always centered on choices made by the maker, and these choices are often determined by values that we would now consider to be far from purely epistemic. Whoever makes the model will already establish many of its epistemic aspects, since different communities have different theoretical commitments and background assumptions. The function of models can be to represent certain things, to educate laypeople and experts, to entertain, and to explain a specific phenomenon. Thus, material models serve both epistemic and non-epistemic purposes at the same time.

The phenomenon to be represented by a model will be idealized to some extent based on the function, the material, the audience, as well as the maker. As with theoretical models, physical models are not true or false, but they are appropriate or inappropriate for a certain function and domain. A crucial aspect of the making of these scientific tools is the process of idealization, which can be understood as a series of decisions rooted in both epistemic and non-epistemic values. One consequence of idealization is that a phenomenon will only be represented partially, and that some aspects will be emphasized, whereas others will be construed differently from the real thing. While these decisions serve the function of the model, this also means that simplification and other idealization methods are not value-neutral choices.

Anatomical models. A popular, and for contemporary sensibilities shocking, example of material models is the so-called anatomical Venus, created by Clemente Susini in eighteenth-century Florence. With these life-sized wax models, he aimed to solve practical and ethical issues in medical training, such as a shortage of cadavers, as well as to educate and entertain laypeople. Even though these models exemplify epistemic values closely related to education and knowledge dissemination, and also serve as faithful truth-bearing *analogies* of the empirical world, many non-epistemic values are present in them. For instance, the models feature Venetian glass eyes, real human hair, and jewelry, and the women were in most cases represented as pregnant. These models thus represent the preferred image of womanhood and beauty, in a way that today would be considered sexist. When the underlying thought process began, certain decisions had to be made about how to represent women, and some of these do not seem to be integral to showing the human body to laypeople and the public at large.

Laboratories. Establishing, designing, and structuring the space and work in a laboratory is a complex issue. As sites of study, learning, experimentation, research, and inquiry, laboratories are evidently epistemic objects, designed by scholars and engineers for epistemic reasons and with epistemic values in mind, such as easy access to materials and a rationalized order of inquiry that fosters reproducibility and systematicity. Nonetheless, the laboratory rarely involves natural objects in their natural environment: they are taken out of context, become standardized, and are represented via images, electrical traces, models, and so on. As Karin Knorr Cetina (1999, 27) notes, “not having to confront objects within their natural orders is epistemically advantageous for the pursuit of science,” since this makes them testable, accessible, and even observable from various perspectives; but when a natural object emerges in the designed context of a laboratory, it surfaces in a “new phenomenal field defined by social agents,” and thus the social order is to some extent transferred to the object as well.[15] Knorr Cetina (1999, 28) discusses various disciplines, for

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[15] On the natural and social order and how they relate to each other, see the collection of Barnes and Shapin (1979). Although the studies in this volume were not motivated by the “science and values” debate, they can be read as a useful discussion and stratification of how natural orders (the targets and subjects of epistemic

example astronomy, which have been transformed from a field science (of personal observation) into an “image-processing laboratory science,” where imaging techniques and the processing of images often reflect local social orders and preferences. Those social orders, as Sharon Traweek (1988) has famously shown, after many years of fieldwork in various high-energy physics laboratories, often exhibit sexist, male-centered structures.

These last few examples can be abstracted to make a more general point. In our expressions, manners of speech, actions, habits, relations to others, clothing, and chosen hobbies and professions, we are often influenced unintentionally and unconsciously by the general *Zeitgeist*, atmosphere, values, and ideologies of the time. Showing how a particular act or idea documents trends of thought and worldviews is the subject of sociology, anthropology, and cultural and feminist studies. In the last few decades, this has played (and still does) an especially important role within philosophy of science, by pointing out many inherent and previously unidentified sexist, racist, and suppressive motives within science itself (Kourany 2010). But besides the usual examples of theories, hypotheses, or data selection, philosophers could even discuss objects and artifacts, as they also document wider tendencies of the time, which may be both non-epistemic and epistemic. If we take a broad enough look at scientific objects, there are abundant examples of non-epistemic values penetrating scientific objects. These include, for example, the historical design of airplane wings as artifacts, shaped by the educational and cultural policies of German engineering and British physicist-mathematicians (Bloor 2011); the social shaping of the theoretical and practical consensus regarding the experimental design of solar-neutrino detection equipment (Pinch 1986); how medicine has changed from a patient-centered bedside science into a professional, doctor-focused clinical practice in the climate of empiricist and observation-based political systems (Foucault 1973/2003).

Zebrafish. The *zebrafish* is a freshwater fish native to South Asia that is very popular as an aquarium animal. Besides that, it is also a scientific object, taken out of context and from its native environment, and bred in dark laboratories under artificial lights. While one could cite various epistemic reasons for working extensively with zebrafish (we know their entire genome and share many biological features with them), the main reasons for using them are non-epistemic. First, up to the fifth day of life, zebrafish are not covered by the European Union’s current Animal Welfare Regulation. Officially, there are thus no ethical questions and no paperwork, which is why zebrafish are seen by many as a perfect test subject or alternative to experimentation on (other) animals. Furthermore, they do not need much lab space, are omnivorous and require little care and feeding (which all comes down to the economic value of cheapness). Moreover, they also reproduce quickly—in contrast to mice, which have around 50 offspring per year, zebrafish can lay 300 eggs per week (a valuable non-epistemic feature, given time constraints on research and publication). Because of these non-epistemic values, zebrafish are considered a viable alternative biological model in labs, and studies on them have consequently multiplied in recent years (Lessmann 2011).

Yet, as noted, zebrafish still boast many epistemic values even after being introduced into the lab: “studies of zebrafish larvae juveniles include examination of organ maturation, physiology, gene expression, disease progression, pharmacology, toxicology, and behavior” (Singleman and Holtzman 2014, 396). Although zebrafish have some unique features regarding their suitability for research (having in mind drugs, for instance), the main reasons

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investigations with epistemic values in the background) interact continuously and even dialectically with various social orders (thereby instantiating non-epistemic takes).

for choosing them (over mice, for example, which have similar, epistemically relevant features, or Drosophila melanogaster, which has also often been used as a model organism in biomedical research) largely come down to non-epistemic values.

4. Parting the ways: the new demarcation problem and materializing values

By calling attention to the material culture of science, we are obviously trespassing on certain *inherited disciplinary boundaries*. Recall from Section 2 that mainstream twentieth-century philosophy of science was, from its inception, concerned with theoretical issues, such as theories, concepts, inferences, and related abstractions. Anthropology, sociology, and science and technology studies have always been more down to Earth in calling attention to the *actual* practices and contexts of the sciences. Mainly independently of each other, however, both the social sciences and philosophy ended up addressing the complex question of values and science. In the 1950s, philosophers started to recognize that scientists qua scientists make value judgments, even in theoretical-justificatory contexts. Meanwhile, sociologists have discussed the question of non-cognitive elements in knowledge production ever since Max Weber's groundbreaking papers, and even more obviously since Robert K. Merton's new framing of the "existential factors" of science. After Thomas Kuhn's seminal work on the history and philosophy of science, sociologists of science and scientific knowledge developed even more sophisticated frameworks and approaches to the question of how values and other typically "non-theoretical" issues of science intertwine and shape knowledge and science itself.

Science and technology studies and the philosophy of engineering and technology, for example, have their own discussions, and one might raise the question of why material culture and its relation to values should be introduced into philosophy of science at all.[16] The reason for introducing concepts, tools, notions, and ideas from one field to another might be that the two fields (or sets of fields) operate under different aims and accept different goals and ideals. In a different context, the philosopher of science Larry Laudan has made a similar point. In discussing the demarcation between science and pseudoscience, he deems simple socio-historical lists of what counts as science or pseudoscience to be useful, though inadequate from a philosophical viewpoint. It is worth quoting him in full:

> We want to know what, if anything, is special about the knowledge claims and the modes of inquiry of the sciences. Because there are doubtless many respects in which science differs from non-science … we must insist that any philosophically interesting demarcative device must distinguish scientific and non-scientific matters in a way which exhibits a surer epistemic warrant or evidential ground for science than for non-science. If it should happen that there is no such warrant, then the demarcation between science and non-science would tum out to be of little or no philosophic significance. (Laudan 1987, 118)

Coming up with descriptively adequate narratives and case studies and delving into related considerations is a very important springboard for philosophy. It is vital to know what scientists count as a value influence, which types of values they rank and recognize, and

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[16] One of our reviewers has raised this question and had a point about the difficulty of connecting different fields, especially about repeating points that have been described in detail elsewhere. For someone interested in the material side of values and learning about the robust tradition of STS scholarship, it makes sense to participate in *that* debate, instead of initiating a new, separate discussion under the aegis of philosophy. Nonetheless, we think that philosophy often (if not always) raises different questions than social studies of science, and even if the questions are the same, the aims and reasons that each discipline considers to be acceptable and fundamental may differ.

how they see their own role in these scenarios. But "philosophic significance" often goes hand in hand with "epistemic warrant," "principled reasons" for taking certain positions, and conceptual entanglements and possibilities in the "logical space of reasons" (to use a Sellarsian term)—i.e., reasons are given and taken, and commitments are being evaluated based on one's normative entitlements. Again, as Laudan (1987, 120) says, "philosophy at its best should tell us what is reasonable to believe and what is not," and that is evidently different from "the taxonomic task of sorting beliefs into two piles" (such as 'science' and 'pseudoscience', or 'epistemic' and 'non-epistemic', one might add).[17]

If descriptive analysis is not enough, philosophy may thus have a chance to offer a unique perspective in the discourse on values, especially through rational clarification and resolution.[18] And we do not really have to search long for such studies, as philosophers of science are already occupied with normative questions about "proper" or admissible ways of how values can influence science. The problem appears explicitly in Sven Ove Hansson's work (2017), and even more recently, the issue has been officially labeled "the new demarcation problem" by Holman and Wilholt (2022), gaining widespread attention. While Hansson's original concern was how to preserve the integrity of science in the presence of value influences, the newer literature has focused on how to allow for a legitimate role of values while keeping the integrity of science intact as much as possible. A small difference, but where we put emphasis matters significantly in the long run; and that is why we need to assess the *character* and *range* of these value influences.

Holman and Wilholt have expressed the bafflement of those scholars who do not know how to proceed and what to do with the "science and values" literature: Even though in certain fields, such as STS and the philosophy of technology and engineering, philosophy may have had a more consensual view on the nature of values and their role, it has only recently fallen into line.[19] Nevertheless, the matter of values has not been settled entirely, with some of the most challenging questions arising at this very point—after all, it is not as if "anything goes;" there are cases of "biased science," recognized by all sides, that "cross a line between inevitable management of epistemic risk in the light of value judgments and an inadmissible distortion of inquiry" (Holman and Wilholt 2022, 211). Thus, the literature still owes us an answer as to how we can tell whether a given non-epistemic value influence is *legitimate* or not. Is there a *principled, rationally justifiable and reasonable* way to claim that this or that effect of values actually distorts the scientific machinery in such a way that it affects or even damages the *integrity* of science? Or, to put it into more normative and

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[17] Note that Laudan, unable to identify any necessary and sufficient conditions for defining science, proclaimed the "demise of the demarcation problem" for lack of any universal and solid demarcation criteria that could function as the foundation of a normative approach.

[18] Normativity might surface in STS as well. Harry Collins and Robert Evans (2002) distinguish three different waves of science studies; the first (1930s-1960s) was characterized by a strong descriptive aim, namely how errors could be captured sociologically through a discussion of the institutional conditions of science (à la Merton, Barber, etc.). The second wave (1970s-2000s) exhibited a new feature by accounting for truth and falsity and rationality and irrationality equally, thus relativizing scientific methods and the borders of science in a broader sense (in the strong program, and other Wittgenstein-inspired programs of sociology). Finally, the third wave (since 2002) aims to reclaim such notions as expertise and knowledge; it has introduced a certain form of normativity into the sociological project of science studies by identifying the differences between true and alleged experts.

[19] Note, however, that philosophy has fallen into line only to a degree, as defenders of the value-free ideal are still around, searching for viable alternatives and ranges of value freedom; most recently, see Stamenkovic (2024).

simplistic terms, the issue comes down to the general worry of how to tell the difference between legitimate (good) and non-legitimate (bad) value influences.

Holman and Wilholt call this the “new demarcation problem.” While previously, the business of demarcation was about the separation of science from pseudoscience (as it was for Laudan), the new demarcation concerns the separation of illegitimate value influences from legitimate ones. This is a general philosophical project that also has normative offshoots: After settling the issue of how to determine influencing factors, we should be able to tell which value influence is legitimate and hence admissible, and which is not. Holman and Wilholt have identified five strategies in the existing literature, and we will follow them here below. Using our examples from the materiality of science, we could go through all of them by checking how the five strategies perform in determining the legitimacy of value influences in each case. However, we will only briefly sketch out how each value demarcation strategy aligns with one of our examples (test tubes), in order to foster a normative debate about the roles of values in science, with a particular focus on materials.

(1) The *axiological approach* is based on a previously agreed set of (freely chosen, though circumstance-dependent) values, and only those influences will be legitimate that are shaped by and related to these values. An example of this is the idea of the inclusion of social values in order to support society’s advancement. The difficulty lies, of course, in how one can determine this “appropriate set of values”; some people would point to the “needs of society,” but these are typically hard to determine and in need of further interpretation and analysis. Intolerant and malicious societies are marked by deteriorating values that should obviously be avoided in a democratic setting.

Thus, this is a normative stance, in the sense that it tells us what should and should not be included in science. As test tubes are necessarily entangled in non-epistemic values, it makes sense to adopt a normative approach to define which non-epistemic values are legitimate in their design, distribution, and use. In the nineteenth century, certain economic circumstances and values enabled a growing volume of glass production in general, and of glass test tubes in particular. This expanded access to test tubes to a wider range of non-wealthy lay people interested in chemistry who previously did not have the means to purchase any instruments whatsoever. Thus, a non-epistemic, contingent value led to greater access to instruments, and in turn to more knowledge being produced by lay people interested in science. One could argue that test tubes supported social advancement, and in this sense they also supported the idea of Janet Kourany’s socially responsible science (Kourany 2010). However, determining whether this is a good thing also requires agreement on the value of demystifying science by widening access to it; if a consensus emerges that this represents a fundamental value, then legitimate measures could be taken to foster it, as happened with test tubes. An economic reason led to an epistemically profitable situation, but the question of whether such “economic reasons” could be generalized and extended to all cases still remains unanswered. It is very rare that we can agree upon the values that become involved, and in the case of material objects, as we have seen, epistemic/non-epistemic values play a collective role. Furthermore, the design, production, marketing, use, and recycling of instruments all require different sets of agreed upon values from different agents involved with each stage of the instrument’s lifecycle. Thus, giving a general explanation and a comprehensive framework seems unfeasible.

(2) Functionalist demarcation strategies look at the *ways* values influence science, and basically argue that certain *modes* are permissible while others aren’t. The most well-

known differentiation in this regard comes from Heather Douglas (2009), who differentiates between the *direct* and *indirect* use of values. Values play an indirect role when they determine the strength of evidence to be accepted for a certain conclusion, and a direct role when they “act as reasons in themselves to accept a claim” (Douglas 2009, 96). Values of ethics and social concerns can legitimately prompt scientists to search for more evidence (as in the case of vaccines, where standards should be higher, than, say, in botany), but they cannot force them to accept a point directly.

Functionalist strategies do not necessarily answer all our concerns, since (a) it is not clear at all which value-influences are allowed to have an indirect influence; and (b) indirect value influences can turn into *direct* influences. In our case, at first glance, the economic factors that facilitated access to glass test tubes seem to be an indirect value influence, which does not affect questions of cognitive content. However, new types of glass have to be tested and understood, and any change has to be scientifically justified and shown not to distort (in unacceptable ways) the scientific process. Thus, material qualities, like the durability and translucency of the glass used, can enhance or distort the properties of test tubes, and with it the quality of observation (recall Schickore’s example of the snake venom from Section 3.3). Thus, according to (b), an indirect value-influence had turned into a direct one; many materials within science are essential not only in order to maintain the process of science, but they also play an essential role in shaping observation and perception as well, resulting in a strict direct/indirect distinction losing its base and seemingly becoming less helpful to evaluate the “rightness” of an influence. Also, imagine the following case: due to certain more practical reasons (costs, reproducibility, accessibility), a huge variation of tubes are being eliminated and only a few favored ones remain in use. Advocating for their usage in actual practice exemplifies the result of certain values, and though this is only an indirect influence (in the sense that we are not making decisions concerning concrete evidence based on values), our values still end up restraining the limited space of possibilities, and the range of possible evidence as well.

(3) So-called “consequentialist demarcation strategies” aim to capture the *consequences* of value influences, based on a post facto determination of their legitimacy. Some argue, for example, that the consequences should coincide with the democratically endorsed aims of scientific research; as Intemann (2015, 218) says, “it is legitimate for scientists to appeal to non-epistemic values insofar as doing so will promote democratically endorsed epistemological and social aims of research.” Yet again, this brings us to a more fundamental discussion of how the search for truth and the democratic ideal constrain each other.

Although in the case of test tubes, more affordable production democratized access to scientific tools, this could not be extrapolated to serve as a norm for material culture. While in some cases, the guiding non-epistemic value should be affordability (for instance, when it comes to vaccine needles, wound dressing, or hygienic and disposable health care items), in other cases, the cost of tools is much more complex. This applies to large-scale technical instruments and complex engineering projects. Most nineteenth-century manufacturers of test tubes, of course, did not produce them for charity and profited from their sale, but the consequence of these non-epistemic values was an epistemic value, i.e., gaining more knowledge and fostering the development of modern-day chemistry. (Also recall the case of new microscopes and spectroscopes that seriously limit access to brand-new scientific research because of their costs and maintenance.)

However, the popularity of glassware (including that of test tubes) led to consequences that would not be considered epistemic advantages. Due to the fragility and other features of the material, much of the chemical apparatus has been destroyed, broken, and reused in various forms, so the history of chemistry and its instruments is far from being comprehensive. Frederic L. Holmes and Trevor H. Levere argue that chemical apparatus is “seldom signed and seldom is especially beautiful: therefore, it is of much less appeal to collectors than are astrolabes and microscopes. More than most laboratory equipment, chemical apparatus is disposable” (Holmes and Levere, 2000, viii). Aside from their less aesthetically pleasing nature, glass is also more fragile than other materials, leading to the change of practice in terms of handling as well. Thus, a consequence of a feature of the material that provided access to it has also resulted in some aspects of the history of chemistry becoming much harder to reconstruct.

But more has to be said by the proponents of this approach to exclude the possibility of overriding an epistemic value in favor of a non-epistemic value. If scientists could achieve a democratically agreed upon ideal with certain values (e.g. embracing regular citizens within the board of science, similarly to bottom-up citizen science projects), then those values are legitimately admitted. But what if those values concern the simplification of material artefacts of science so that regular citizens could access them, which in turn ends up contributing to serious epistemic distortions in their functioning?

(4) The fourth strategy is called “coordinative.” According to this view, we should look “at whether value-laden methodological choices are appropriately aligned with the expectations that are placed on them by others” (Holman and Wilholt 2022, 213); with the so-called “others” referring to members of the public or fellow-scientists. In the latter case, breakdown of expectations includes situations where one violates or dissents from established conventions of risk management. But to keep up the trust in the collective (by not violating rules individually and in an ad hoc manner), people have to coordinate their values, expectations, and unconventional moves: their ways of doing and talking about science that dissents from the locally institutionalized norms. That is, science always has to balance the essential tension between individualist revolutionaries and collectivist traditionalists, and if anyone moves over to the other side, they have to present good reasons to both the scientific community and the public. In the former case, members of the public also have expectations and presumed knowledge of how science evolves, decides, and produces knowledge, but as science is flexible in so many ways, coordination is required between the contextually defined and evolving strategies of scientists and the public. One such way is to foster transparency about values in the various stages of the scientific process (Elliott 2022).

Innovation within science, such as developing new techniques and craft skills (like glassblowing in the case of new tubes) or creating novel tools and instruments are often done without publicly announcing them during the process of their evolution and blossoming. One could have various reasons to do so: as the Scottish publicist John Griffin’s goal was to broaden the scope and accessibility of chemistry, it made sense for him to support the development and popularization of new craft techniques that provided much better means for observation, measurement, and experimentation than previous instruments. Similarly, when Faraday joined some of his peers in “introducing cheap, home-blown glassware as an alternative to the expensive and highly specialized glass apparatus of French chemists” (Werrett 2019, 177), his goal was to change laboratory techniques. It would also be easy, however, to list cases from the history of science where technological innovation was driven mainly by such non-epistemic factors as individual fame and progress, national interest and campaign, economic development, or personal struggle and hatred among colleagues.[20]

As soon as they reach the stage of sharing with their intended audience (the public or fellow scientists), coordination begins. In the first case, epistemic motivations of scientists are easier to coordinate with the epistemic demands of the public or colleagues, although one could easily imagine clashes between those ideals (e.g. the public fostering simplicity on the one hand, while scientists are aiming for precision on the other). In the other cases of innovation, non-epistemic values that drove the whole process had to be coordinated with official epistemic concerns when results were presented to the public or got published for the assessment of fellow scientists.

Nonetheless, as Resnek and Elliott (2022) note, one has to offer systematic and comprehensive reasons or propose local and case-related arguments. But, on the one hand, given the multi-faceted nature of science and its instruments, fixed and universal standards do not seem to work; and on the other, case-by-case coordinations bring us back to a less-principled stage of inquiry, and the possibility of being transparent about all the nuances that enter a *particular* situation is at least doubtful.

Furthermore, as discussed in the previous section that described consequentialist demarcation strategies, the advantages and the disadvantages of the material in the case of test tubes had to be aligned in some way. While ceramic was apparently more durable, it was not see-through and it could not be recycled. On the other hand, while glass was see-through and relatively cheap to produce, it was nonetheless very fragile and recycling it made the material less and less durable. Coordinating the features of and the proposed epistemic values of certain materials and instruments then also meant an implicit or explicit coordination of the scientist's priorities as well, but reconstructing all these issues is not an easy task.

(5) The final approach is called the "systematic strategy" because it focuses on the scientific community, rather than individual scientists and their individual projects. Taking their clue from social epistemology, Holman and Wilholt (2022, 214) have written that "biases and distortions on the individual level are unavoidable and that serious epistemic damage only arises at the social level, when the community as a whole lacks the structure to critically address them and to sustain the mechanisms of self-correction."

This approach is consistent with the most normative takes on how to analyze the role of values in the material culture of science. As it is tied to social epistemology, it reflects how communities with different skills, epistemic backgrounds, implicit and explicit expectations, hypotheses, and goals contribute to the development, design, distribution, repurposing, and use of instruments. Tools in science are constantly evolving; they are redesigned, repurposed, maintained, repaired, cared for, and handed down to other scientists. These practices are not only influenced by both epistemic and non-epistemic values (for instance, when it comes to repair practices), but also represent different aspects

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[20] One recent example comes from the history of oceanography where numerous technological devices and innovations – including radars, sonars, submarines – were officially developed to pursue epistemic goals, but behind the scenes the bills were paid by governmental and military offices for reasons of national security; see Oreskes (2021). Although personal and subjective motivations could have been more epistemic, the whole research was in the end made possible (even institutionally) by governmental bodies and funds – because of this Janus-faced situation, scientists who were involved in the process in the mid-century were still struggling even after the millennium to coordinate the various values and motives, according to Oreskes' experience and interviews with the actors.

of scientific inquiry. But the question remains: if value-influences are admitted on the societal level, that is, values – as discussed by Longino (1990) – emerge from a social setting of discussions through criticism and questioning, how do we account for such special artefacts that are being promoted by the companies that have the most economic resources they can mobilize in order to advertise their products - thus influencing and shaping mainstream, general discussions? As Resnik and Elliott (2022) have shown, in the case of chemical issues, where private, market-oriented companies are able to make use of significantly larger amounts of financial and human resources, they have a better chance to "emerge victorious" in a debate on a systematic level against a moderate governmental campaign. The same can be repeated with many anti-scientific governmental acts that still have way more chances to shape a systematic strategy than an NGO or a smaller, non-profit scientific board (as shown by numerous examples from the populist regimes of Great-Britain, the United States, Brasil, Slovakia and Hungary).

5. Conclusion

The paper has related the material culture of science to the new demarcation problem and tested the five approaches discussed within the new demarcation problem on the example of test tubes for a possible value-sensitive approach to scientific instruments. As Holman and Wilholt (2022, 214) admit, these are not necessarily competing views; one does not have to choose just one to work with, and "it may be the case that a satisfying solution combines more than one of these ideas." But all of these points could provide guidance on future research into the role of values, especially in the context of materials within science. That said, the philosophical discussion of values in science could be genuinely enriched by broadening the traditional theory-concept-argument perspective, and by embracing many of the hard-won descriptive insights of material culture and science and technology studies. Doing so would not be a simple reiteration of one field's concerns and ideas, since philosophical inquiry—more often than not—pursues different interests, methods, and aims. Previously, Barry Barnes (1982, 63), among many others, has noted that "the normative concerns common among epistemologists are difficult to reconcile with an empirical orientation to science." Taking this from the other end, we think that philosophical discussions are in serious need of an injection of empiricism (also Alan Richardson's program) to substantiate and anchor philosophy's rational clarifications and resolutions in the practical world. In fact, this point has already been noted among those discussing science and values, and we have argued only that it ought to be broadened to include other important empirical things, such as materials.

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