Focus: Supplied Knowledge: Resource Regimes, Materials, and Epistemic Tools

Introduction: Reconsidering the Resources of Epistemic Tools

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Abstract: This introduction to the Focus section "Supplied Knowledge: Resource Regimes, Materials, and Epistemic Tools" provides a framework to analyze critically the ways in which knowledge depends on material supplies. It claims that most scientific technologies of the early modern and modern periods were made possible only by the steady supply of a large variety of so-called natural resources and that the practices necessary to exploit, process, and provide these resources in the quality and quantity required were closely linked with the scientific and humanistic agendas of their time. The essays assembled here examine select epistemic tools and key materials from which these were made. This introduction shows how the essays apply different scales to reveal the local and global values, epistemic concepts, aesthetic ideals, social systems, (geo)political constellations, and economic frameworks that have co-constituted the making of scientific instruments, artifacts, and knowledge in and beyond the Global North.

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Today's news is full of reports about what economists call a resource crisis. Interruptions in semiconductor and microchip supply chains are affecting every industry. Wood shortages are notably paralyzing paper production. Rising oil and gas prices are endangering the energy sector and widening the poverty gap worldwide, deepening anxieties about political disintegration. Fueled by the pandemic and war, this crisis is heightening awareness of the global exploitation, waste, and unequal distribution of material resources. It is reinforcing concerns about environmental pollution, climate change, and working conditions along transnational supply chains. And it is giving new urgency to questions of how the consumption of resources can be sustainably reduced in the technology sector—and thus also in science.

The development and use of new, fair, and green scientific technologies is the order of the day.[1] However, the current crisis also points to deeper frictions with and around materiality in our knowledge cultures. The ways in which so-called natural resources are handled have changed over time, influenced by diverse epistemic, economic, political, and geophysical conditions. Historians of science thus have much to contribute to current debates by unlocking this long and complex history, for the extensive resource exploitation of modernity would not have been feasible without ever-growing scientific expertise; and, conversely, the richly equipped laboratories, scientific libraries, and collections of the modern period would not have been possible without the abundance of available materials. This Focus section consolidates existing studies on the issue and provides new impetus for such analysis by addressing the geographic provenance, procurement, and application of material resources used in the making of scientific and humanistic tools.

Etymologically, the word "resource" derives from the Latin verb "*resurgere*," meaning "to resurrect, rise up, or recover," in the context of war or cycles of crisis. But to some extent, our current understanding of resources emerged from the Christian philosophy of the self. With the rise of Christianity, the Latin term was used for centuries to describe Christ's resurrection and, subsequently, a God-given human capacity of spiritual rebirth, of emerging from an internal crisis. The Old French "*resorse*," then, referred more generally to individual abilities that were seen as helpful in adverse circumstances. From the early seventeenth century, this concept of resources was externalized from the inner to the outer world, and resources were viewed as materials with the potential to meet human needs. The term came to apply to material substances of the old and newly discovered worlds that were identified, extracted, and processed to enrich individuals, companies, and governments.[2] Yet it was not only political and economic forces that contributed significantly to this understanding of material substances as a "natural resource" and their modern economic fruit, "natural capital": the sciences, too, have played an important part. As recent scholarship has shown, the administrative sciences, geosciences, and (proto)industrial sciences of the eighteenth and nineteenth centuries advocated for a new "spirit of quantification"

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and continued our inspiring discussion in a workshop at the Max Planck Institute for the History of Science in June 2022. We thank all of our authors for their continued enthusiasm for this collective project. Special thanks go to Michael Thomas Taylor for his excellent language editing. Two anonymous referees have provided thorough comments, for which we are most grateful. Finally, we thank the *Isis* Editors and their team for their support and encouragement.

[1] See, e.g., Ritu Singh and Sanjeev Kumar, eds., *Green Technologies and Environmental Sustainability* (Cham: Springer, 2017); and Chris Forman and Claire Asher, *Brave Green World: How Science Can Save Our Planet* (Cambridge, Mass.: MIT Press, 2021).

[2] Entry on "resource, n," OED Online, June 2022, Oxford Univ. Press, https://www.oed.com/view/Entry/163768?rskey=yoLxvg&result=1&isAdvanced=false (accessed 19 Aug. 2022); and Daniel Hausmann and Nicolas Perreaux, "Resources: A Historical and Conceptual History," in *Discourses of Weakness and Resource Regimes: Trajectories of a New Research Program*, ed. Iwo Amelung, Hartmut Leppin, and Christian Müller (Frankfurt am Main: Campus, 2018), pp. 179–208.

that led to a global inventory and classification of fauna, flora, minerals, and populations. In the twentieth century, various data-driven sciences followed suit, first fostering a global and exploitative policy of resource use and then, beginning in the 1960s, laying the foundation for a new policy of "resource protection"—though the neoliberal concept of resource protection is an oxymoron that retains the framework of an economically usable nature.[3]

In response to this literature, the present Focus section illustrates that an even broader range of academic disciplines drove these processes of natural resource exploitation forward—through the choice, use, and maintenance of their respective epistemic tools. Since the early modern period, most scientific and humanistic research has relied on a plethora of epistemic tools, from humanistic media and everyday objects to scientific instruments and high-performance technologies; and the production and continued refinement of these tools has required a wealth of material substances from around the world, including various kinds of wood, waxes, metals, clays, sands, and rare earths. Our guiding hypothesis is thus that the knowledge cultures being examined here were possible only thanks to the steady supply of a large variety of resources and that the practices necessary to exploit, process, and provide these resources in the quality and quantity required were closely linked with the scientific and humanistic agendas of their time. Accordingly, we apply different scales to reveal the local and global values, epistemic concepts, aesthetic ideals, social systems, (geo)political constellations, and economic frameworks that have co-constituted the making of knowledge in and beyond the Global North.

Overall, this Focus section maps a wide range of materials and their uses in producing knowledge and traces *longue durée* changes in how such resources were exploited, processed, and further used. Each of the contributions addresses a specific technological artifact. In so doing, they explore what kinds of materials were needed and consider why and how local means and knowledge practices intersected with global infrastructures to satisfy these demands. Following the materials across regions, oceans, and continents, the authors reveal conceptual choices and dynamics of competition that were not at all linear but were in fact connected to various sorts of unexpected activities; often, these contingencies were triggered by the materials themselves. The artifacts examined include telescope lenses and test tubes made of transparent glass (Sven Dupré), silver money as a medium of knowledge and governance (Sebastian Felten), white porcelain figurines that were key to neoclassical knowledge formation and the training of European taste (Suzanne Marchand), stainless steel tuning forks introduced in psychological experiments (Fanny Gribenski and David Pantalony), wax-based cylinders applied in scientific sound recording (Viktoria Tkaczyk), and paper forms for data processing (Christine von Oertzen). Finally, our Focus section discusses questions beyond supply and procurement and reflects on issues of maintenance, repair, reuse, and waste in early modern and modern times (Simon Werrett).

The essays build on and expand recent work in various areas of the history of knowledge, including scholarship in art history and media studies that has singled out materials such as silicon, mercury, and horn, exploring their use in twentieth-century art and digital industry.[4] Related scholarship has also pointed to the diverse and often nontransparent geographical provenance of the "natural resources" used by twentieth- and twenty-first-century technology firms

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[3] Theodore M. Porter, "Making Things Quantitative," *Science in Context*, 1994, 7:389–407; Lea Haller, Sabine Höhler, and Andrea Westermann, "Einleitung: Rechnen mit der Natur: Ökonomische Kalküle um Ressourcen," *Berichte zur Wissenschaftsgeschichte*, 2014, 37:8–19; and Lissa L. Roberts and Simon Werrett, eds., *Compound Histories: Materials, Governance, and Production, 1760–1840* (Leiden: Brill, 2018).

[4] Jennifer Gabrys, *Digital Rubbish: A Natural History of Electronics* (Ann Arbor: Univ. Michigan Press, 2011); Henrik Selin and Noelle Eckley Selin, *Mercury Stories: Understanding Sustainability through a Volatile Element* (Cambridge, Mass.: MIT Press, 2020); and Henning Schmidgen, *Horn; or, The Counterside of Media* (Durham, N.C.: Duke Univ. Press, 2021).

and builders of major media infrastructures.[5] Our case studies show that the making of scientific artifacts has for centuries depended on local and global delivery systems and that in the past these processes have sometimes been anything but transparent. What is more, the natural sciences and humanities did not just benefit from the increasing diversity of goods, global trade, and manufacturing industries. From the seventeenth to the early twentieth century, many scholars, scientists, instrument-makers, technicians, and artists have also been deeply invested in the material properties of their research tools. To employ these properties for their own purposes, they themselves started to inventory, taxonomize, and exploit the richness of the natural world. Through this subjugation of nature, they contributed to a political episteme that claimed authority to define material resources as either raw or cooked, natural or artificial, ubiquitous or rare, dead or active.

This discourse on resources took shape in all fields of research and can be teased out retrospectively from laboratory notebooks, patents, and handbooks, as well as recipes, shopping lists, memo slips, account books, and bureaucratic records. Certainly, some of these documents were kept under wraps for business reasons, such as in early modern Venetian glassmaking (Dupré) or modern porcelain production in the city of Meissen in Saxony (Marchand). In other fields of knowledge, however, material competence was explicitly exhibited to enhance the authority of the objects in question. The labor-intensive production and testing of silver money, for instance, was a popular motif on seventeenth-century Dutch coins, showcasing the ongoing effort necessary to create lasting trust in the currency's stability (Felten); nineteenth-century instrument-makers stamped the provenance of their stainless steel on their artifacts as a promise of experimental precision (Gribenski and Pantalony); and twentieth-century sound archivists divulged their knowledge about the various waxes used for cylinder recording production as a way to underscore the durability of their archiving devices for long-term preservation, much to the chagrin of the phonograph industry (Tkaczyk).

Knowledge about materials and their procurement was for centuries shared both silently and explicitly, because this knowledge ultimately formed the very basis of scientific experimentation, observation, and documentation. As our Focus section reveals, both natural scientists and humanists, from astronomers and philologists to bureaucrats, psychologists, and musicologists, became true experts on the chemical-material composition of their working materials, making chemical analytical skills one of the core proficiencies of knowledge production. From the early modern period, chemical expertise thus partially began to replace magical, symbolic, or symbiotic notions of material substances.

However, our *longue durée* time frame also exposes a profound change in resource economics: while resource extraction has existed for centuries, many early modern experimenters used materials sparingly and for various purposes, drawing on the belief that humans, animals, and materials form part of a single "oecomomia" (in the sense of an extended household) that must remain in balance.[6] In contrast, the epistemic values and aspirations of nineteenth-century scientific culture, such as precision, purity, and standardization, prompted ever more highly specialized demands of materials for scientific instrumentation. Paper, for one, was part of an extremely thrifty resource economy in the early modern period; it was made from worn garments and could serve many uses beyond being a medium for reading or inscription. The expanding book market

[5] Jussi Parikka, *A Geology of Media* (Minneapolis: Univ. Minnesota Press, 2015); and Nicole Starosielski and Janet Walker, eds., *Sustainable Media: Critical Approaches to Media and Environment* (New York: Routledge, 2016).

[6] For an in-depth exploration of alternative material economies in the early modern period see Simon Werrett, *Thrifty Science: Making the Most of Materials in the History of Experiment* (Chicago: Univ. Chicago Press, 2019); and "Resources in the Early Modern World," an *Isis* Focus section, edited by Sebastian Felten and Renée Raphael, scheduled for the September 2023 issue.

of the sixteenth and seventeenth centuries required large quantities of paper, which was made from any available scrap of linen; old books and used, perishable paper, in turn, served as baking or toilet paper, as insulating material, or for powdering wigs and curling hair (Werrett). In the modern period, then, paper was increasingly viewed as a specific tool that had to be custom-made for particular uses in a highly standardized and controlled manner. The enumeration forms for nineteenth-century Prussian census taking, for example, were single-purpose tools, cut to size from paper produced on demand according to specific instructions issued by the Prussian census bureau, and their material robustness was regularly checked using chemical and mechanical testing methods (von Oertzen).

But there certainly are counternarratives to such a linear development from the thriftiness of early modern knowledge cultures to the specialized and often wasteful uses of resources in the sciences of modernity. The Venetian-style *cristallo* glass used by Galileo Galilei for his iconic telescope serves as such a counterexample. Marking the beginning of a highly professional glass culture, Italian *cristallo* glass could only be made using carefully selected substances—sand, soda, lime, and manganese—from specific locations in Europe and the Levant; and the wooden blast furnaces of the Venetian glassmakers further symbolized this early modern transition from glassmaking in the domestic kitchen to glassmaking in the professional workshop, where fine telescopic lenses and thus new epistemic tools were created. There was a brief return to the laboratory kitchen in the early nineteenth century, however, exemplified most saliently in the field of chemistry, when scientists made their own test tubes and recycled the glass materials they used, before new companies once again began to manufacture and market standardized laboratory materials (Dupré).

More generally, this Focus section discusses what we gain from expanding our view from the "nonhuman agents" and "technical things" of scientific settings, a much-discussed issue in recent decades, to the material *a priori* of these and other settings of knowledge production.[7] Science and technology studies scholars and historians of science have strongly emphasized the fact that research technologies neither come out of nowhere nor exist as stable objects. They result from long procedures of instrument making, and scientists are actively involved in the design, use, improvement, reuse, repair, recycling, transfer, and disposal of technological things.[8] By widening our lens to encompass practices of procuring and securing material supplies as well as the engagement with the relevant materials and kinds of matter, we further expand the notion of "object biographies" on a temporal, geopolitical, and moral scale. Here, the question arises as to where such a material history of scientific artifacts should begin. Who or what determines the source material, the resource, the raw material, the natural substance, or the feedstock? And how can the historiography of scientific artifacts do justice to the claim of New Materialism to once again ascribe an inherent capacity for action to the material substances declared "dead," "raw," and "passive" by humans in the age of the Anthropocene?[9]

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[7] Regarding nonhuman agents see Bruno Latour, "Nonhumans," in *Patterned Ground: Entanglements of Nature and Culture*, ed. Stephen Thrift and Steve Harrison (London: Reaktion, 2004), pp. 224–227; on technical things see Hans-Jörg Rheinberger, *An Epistemology of the Concrete: Twentieth-Century Histories of Life* (Durham, N.C.: Duke Univ. Press, 2010), pp. 217–232.

[8] Lorraine Daston, ed., *Biographies of Scientific Objects* (Chicago: Univ. Chicago Press, 2000); Nelly Oudshoorn and Trevor Pinch, eds., *The Co-Construction of Users and Technology* (Cambridge, Mass.: MIT Press, 2003); Pamela H. Smith and Benjamin Schmidt, eds., *Making Knowledge in Early Modern Europe: Practices, Objects, and Texts, 1400–1800* (Chicago: Univ. Chicago Press, 2007); Cyrus Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (Cambridge, Mass.: MIT Press, 2011); and Bernadette Bensaude Vincent, Sacha Loewe, Alfred Nordmann, and Astrid Schwarz, eds., *Research Objects in Their Technological Setting* (London: Routledge, 2017).

[9] Manuel DeLanda, *A Thousand Years of Nonlinear History* (New York: Zone, 1997); Jane Bennett, *Vibrant Matter* (Durham, N.C.: Duke Univ. Press, 2010); and Tim Ingold, *The Perception of the Environment: Essays on Livelihood, Dwelling, and Skill* (London: Routledge, 2021).

The essays in this Focus section show that early modern and modern scholars did not view their material as exclusively raw or passive. Quite the contrary; they—opportunistically—took advantage of the material's own life, its own logic, and its own temporality. The geophysical deep time of metals, for instance—their millennial age—was a defining aspect of the aesthetics of seventeenth-century silver coins; and the consistence of silver, which appeared in a wide variety of alloys and resisted uniform coin production, later became a much-discussed topic in numismatics (Felten). The whiteness of kaolin, a clay rich in aluminum silicate, was considered very valuable in porcelain manufacturing and led to a processing practice strongly oriented toward the delicate and rare material (Marchand). And the short shelf life and susceptibility to wear and tear of wax prompted the phonogram industry and sound archivists to respect the materials' limits and find new alternative substances (Tkaczyk).

Yet while the agency of particular materials exerted great influence on the making of epistemic tools, scholars and scientists also determined the value and characteristics of the materials in use. In addition to existing, mainly text-based reconstructions of such economies of value, our Focus section benefits here from provenance research in museum curatorship. As Fanny Gribenski and David Pantalony show in their essay, a nineteenth-century tuning fork at Harvard's Collection of Scientific Instruments bears the initials of its Parisian maker, R.K. (Rudolph Koenig), as well as a stamp from Sheffield, the British city where pig iron from Sweden was processed into high-quality stainless steel, which was then used to make scientific instruments. But the fact that the value of steel increased enormously on this geographic journey from Sweden to Sheffield, and then on to Paris or Cambridge, was not only due to the various processing and shipping costs; manufacturers of scientific instruments like Koenig purposefully produced and used the supply chain narrative to enhance the value of the instruments and sell them globally.

By addressing such "chains of value," then, our Focus section also contributes to recent work on the history of supply chains, material flows, and assembly codes,[10] while simultaneously historizing and challenging the praxis of thinking *in* and *with* chains. As Simon Werrett writes in the concluding essay, chain narratives suggest the existence of an initial "raw material," a series of smooth processing and delivery steps, and a clear target of resource use. We find such a user-oriented understanding of both cultural and material resources in the Berlin Phonogramm-Archiv, which at the beginning of the twentieth century aimed to collect "endangered" languages and music worldwide and to treat them as resources of Western European humanities scholars, just as the material resources—delivered from all over the world—enabled the archivists to produce the required record cylinders in the same period (Tkaczyk). But as various contributions in this Focus section show, history is also rich with examples of more frugal and local resource economies. In addition to paper and cardboard (von Oertzen, Werrett), old glass (Dupré) and worthless coins (Felten) were recycled and variously reused in other contexts. In these cases, the epistemic tools of bygone eras themselves became raw material for new and, at least sometimes, more parsimonious and accessible cultures of knowledge. Another case of repurposing is the bright white porcelain figurines that depicted figures of ancient mythology in the neoclassical era and adorned aristocratic salons as precious pieces of decoration and evidence of a classical education. Beginning in the late eighteenth century, porcelain production gradually industrialized and ever-cheaper substitutes were found for the costly material kaolin, until, in the mid-twentieth century, inexpensive toy dolls were made of white porcelain, forming part of a process that Suzanne Marchand calls the "democratization of whiteness."

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[10] Matthew Hockenberry, Nicole Starosielski, and Susan Zieger, eds., *Assembly Codes: The Logistics of Media* (Durham, N.C.: Duke Univ. Press, 2021); and Monika Domann, "Handling, Flowcharts, Logistics: Zur Wissensgeschichte und Materialkultur von Warenflüssen," *Nach Feierabend: Zürcher Jahrbuch für Wissensgeschichte*, 2011, 7:75–104.

This Focus section thus scrutinizes the resource regimes, value chains, and power structures from which epistemic tools of the early modern and modern periods emerged and by which they are renewed. In focusing on telescopes, test tubes, objects made of porcelain and paper, silver coins, tuning forks, and wax cylinder records, we have selected epistemic tools that had a fundamental impact on early modern and modern cultures of knowledge, shaping the sciences, the humanities, and everyday knowledge alike. This also allows our case studies to cover a long period of inquiry. Still, we recognize that this selection is only partial. Given the plethora of mineral, animal, and plant materials that have been exploited for scientific instrumentation and knowledge making worldwide, we can cover only a limited range of materials and the research agendas, practices, and scientific cultures with which they are entangled. We hope, therefore, that these seven glimpses into the fruitfulness of this approach will be taken as inspiration for more in-depth and critical examinations of the contexts of extraction, production, provision, reuse, and forgoing of working materials for epistemic tools.