Materials and Skills in the History of Knowledge: An Archaeological Perspective from the "Non-Asian" Field

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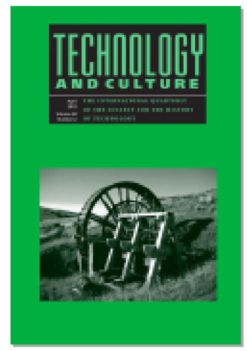

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FORUM: HISTORY OF SCIENCE, TECHNOLOGY, AND MEDICINE: A SECOND LOOK AT JOSEPH NEEDHAM

Materials and Skills in the History of Knowledge

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MAIKEL H. G. KUIJPERS

ABSTRACT: This essay assesses the connections between craft, science, and technology, which I explore through the notion of skill. In particular, what we can learn from studying things and materials? Where do the properties of materials fit in the history of science and technology? Materiality, I argue, allows for a synthetic kind of thinking in line with the approach taken by Joseph Needham in his seven-volume Science and Civilisation in China (1954–84). A methodology is proposed that seeks to harmonize science and craft knowledge, and offers a potential route through which the relationship between social and material phenomena may be explored.

Needham's In-Betweenness

Reading Joseph Needham is to travel through the great in-between. Originally trained as a biochemist, he strayed in between disciplines, turning himself into a historian and sinologist. His early mechanistic views blurred into organicism and provided him with a position in between mechanism and vitalism.[1] His Marxism is of a heterodox variety, maneuvering in between several theoretical models and religion.[2] As a public intellectual he capably positioned himself in between academia and the

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1. Donna Jeanne Haraway, *Crystals, Fabrics, and Fields: Metaphors in Twentieth-Century Developmental Biology* (New Haven, 1976); Carla Nappi and McKenzie Wark, "Reading Needham Now" (in this issue).

2. Gregory Blue, "Joseph Needham, Heterodox Marxism and the Social Background to Chinese Science," *Science & Society*, 1998, *62*:195–217.

public. Fundamentally, he moved in between China and Europe. This inbetweenness makes Needham a hard figure to define and his thinking convoluted.[3] At the same time, this is exactly what makes him so interesting.

In this essay I wish to address Needham's position in between the history of science and the history of technology, and to follow with a methodology of my own that is in line with his. Through the use of *perceptive categories*, I maneuver in between the two epistemic structures of science and craft (technology).[4]

Blurring the Boundary between Science and Craft

As an archaeologist, my interest is in the development of human cognition and the formulation of knowledge over time. My main study concerns metalworking technology in the Bronze Age, fleshing out the character of prehistoric skills. To do so I need to work with scientific methods that draw information from prehistoric artifacts, such as compositional analyses and metallography. Thus, the goal is to explore the character of prehistoric craftsmanship and skills; for my data I have only scientifically acquired evidence to work with. Needham struggled with the reverse. He had evidence of craftsmanship and skill to work with, yet his goal was to explore the character of science.

Whereas in his earlier work Needham attempted to uphold a distinction between science and technology, soon enough this all but disappeared: "one cannot separate science from technology . . . the two intertwine inextricably."[5] Needham was on to something here, blurring the boundaries between science and technology. However, to Needham this seems to have been more of a necessary evil than an interesting observation worth of inquiry.[6] Rather

3. H. Floris Cohen, "Editor's Introduction," *Isis*, 2019, *110*:91–93.

4. Technology is a core topic, if not the raison d'être, of archaeology. There are thus many and changing views of what technology is. Here I use the term interchangeably with craft, based on the Greek concept of *techne*.

5. Needham makes a clear distinction in *Science and Civilisation in China* (Cambridge, 1954), 1:238, and in *The Grand Titration: Science and Society in East and West* (London, 1969), 51. He argues against such a distinction in Needham, "The Historian of Science as Ecumenical Man: A Meditation in the Shingon Temple of Kongosammai-in on Koyasan," in *Chinese Science: Explorations of an Ancient Tradition*, ed. S. Nakayama and Nathan Sivin (Cambridge, Mass., 1973), 1–8, at 3; Needham, Ling, and Robinson, *SCC*, 4.1:241.

6. A contemporary of Needham, Cyril Stanley Smith, was far more outspoken about the close connections between science, technology, and art; see Smith, "Art, Technology, and Science: Notes on Their Historical Interaction," *Technology and Culture*, 1970, *11*:493–549; Smith, "Metallurgy as a Human Experience," *Metallurgical Transactions A*, 1975, *6*:603–23; Smith, *From Art to Science: Seventy-Two Objects Illustrating the Nature of Discovery* (Cambridge, Mass., 1980). Interestingly, these two scholars, equally broadly versed in the sciences and humanities, make few references to each other.

than exploring how technology and science or knowledge and practice are intertwined, he used this inextricability to couple Chinese technology to Western science.[7]

Here, too, it is difficult to pin down where exactly Needham stands. He was aware that technology spreads differently (and perhaps more easily) than theoretical ideas, and that an invention such as the wheel can hardly be called applied science.[8] Furthermore, he realized very well "how far practical technique can reach beyond theory" and likely saw the tensions between these two types of knowledge.[9] Needham again positions himself in between, connecting disparate fields, but my reading of this is that he was conflicted about this topic. Analytically, he viewed the notion of technology as applied science as a "dreadful dichotomy."[10] Strategically, however, he was dependent on it for the sake of his argument. Needham *needed* to keep science, technology, and crafts close because the latter two had to work as proxies for science, and it was through this that he was able to accommodate his claim that China had a scientific tradition lying *behind* the observable advanced level of craftsmanship.[11]

While blurring of the boundaries is defensible, in my opinion he turned the observed connection on its head. Science is a particular abstraction of craft knowledge, not a prerequisite. Skill is tacit, physical knowledge *and* a route to mental understanding.

The Metal Needs to Relax

Exploring the knowledge and skills of prehistoric metalworkers—through their objects—forced me to think about the different characteristics of two types of knowledge identities: those of craft and of science. Studying the manner in which metals are worked—perfectly in line with my interest in skill—I struggled to harmonize skill with the data that the archaeometallurgical discourse was producing. The accurate and precise scientific categorization used in this field was overly abstract and anachro-

7. Cf. Francesca Bray, "Science, Technique, Technology: Passages Between Matter and Knowledge in Imperial Chinese Agriculture," *British Journal for the History of Science*, 2008, *41*:319–44.

8. Needham, *SCC*, 1:238.

9. Joseph Needham, "The Evolution of Iron and Steel Technology in East and Southeast Asia," in *The Coming of the Age of Iron*, ed. T. A. Wertime and J. D. Muhly (New Haven/London, 1980), 507–41, 532. He briefly alludes to the tensions in *Hand and Brain in China*, where he compares Yang fa, "the foreign way of doing things" (science), with Thu fa, "earth methods" (craft, or local knowledge). Needham et al., *Hand and Brain in China* (London, 1971), 16.

10. Joseph Needham, *Science and Civilisation in China* (Cambridge, 1971), 4.1:xxix.

11. Cf. Nathan Sivin, "Review of *Science and Civilisation in China. Volume 7, The Social Background. Part 2, General Conclusions and Reflections*," *China Review International*, 2005, *12*:297–307, at 300.

nistic. How I became aware of this, during a metalworking workshop that I attended to study skill in action, is a useful anecdote to tell.

While working on a chisel, I was instructed to hammer-harden and then anneal it. Instead of going about this right away, I asked why annealing was needed and how the metalworker knew when annealing was necessary. Moreover, I started to extol the science behind the fascinating metallurgical processes that take place in the metal when annealed. The metalworker's response, to my surprise (and momentary dismay), was apathetic. He had little interest in my scientific commentary about his instruction. His expression conveyed the clear message that if the chisel was to get finished, I needed to stop talking about it and work on it. He did offer a few interesting explanatory words, however: "The metal needs to relax."

This simple utterance subsequently became formative in the development of a theoretical framework and methodology for my work. This metalworker expressed a clear understanding of the process that happens during annealing, but from a sensory engagement with the material and how it behaves. This made me realize that to use material science to explore a prehistoric craft, some sort of translation was needed. From that point onward, I stopped thinking about scientific knowledge as being dichotomous with craft knowledge. This was the same *material knowledge*, but categorized differently. To a craftsperson, it is not a necessity to precisely understand what causes a raw material to perform in a certain manner and why. What matters is that they recognize the relevant changes and act upon them. This is a small but important nuance, one that takes into account the properties of materials in knowledge production, and which allows archaeologists to look for skilled behavior without presupposing conceptual knowledge.

The Why and How of Skill

Why is the study of skill so relevant for archaeology? Models of the transmission of knowledge are important to contemporary debates on the use and circulation of metal.[12] Currently, the shape and content of this knowledge are rarely debated. Instead, there is the assumption that metalworking was practiced by skillful specialists. Socioeconomic models of Bronze Age economies rely heavily on this notion of specialized metalworkers but sorely lack in archaeometallurgical data to substantiate the existence of these skillful persons.[13] The presence of skill is argued for on

12. Miljana Radivojević, M. Roberts, E. Pernicka, Z. Stos-Gale, M. Martinon-Torres, T. Rehren, P. Bray, D. Brandherm, J. Ling, J. Mei, H. Vandkilde, K. Kristiansen, S. Shennan, C. Broodbank, "The Provenance, Use, and Circulation of Metals in the European Bronze Age: The State of Debate," *Journal of Archaeological Research*, 2018: 1–55.

13. Tobias L. Kienlin, "Copper and Bronze: Bronze Age Metalworking in Context," in *The Oxford Handbook of the European Bronze Age*, ed. S. H. Fokkens and A. Harding

the basis that metalworking is considered a demanding and complex technology, involving specialist knowledge.[14] Childe even identified the Bronze Age, and metalworking in particular, as "the beginnings of science."[15] These views echo Joseph Needham's position that there must be science behind craftsmanship.

If archaeologists are to say anything substantial about skill, and to push our understanding of skill beyond circumstantial theoretical arguments, it needs to be firmly based in empirical observations of artifacts. Despite increasing engagement with archaeological questions, a gap remains between archaeometallurgical specialists and mainstream archaeologists. Several of the leading scholars in archaeometallurgy were not trained in archaeology but came to the field from the natural or material sciences.[16] This problem relates to a wider debate in archaeological studies of technology. In broad brushstrokes there are two distinct frameworks in which prehistoric technologies are studied: a material framework and a social framework.[17] The former is universal and works via the scientific analysis

(Oxford, 2013), 414–36; David Killick and Thomas Fenn, "Archaeometallurgy: The Study of Preindustrial Mining and Metallurgy," *Annual Review of Anthropology*, 2012, *41*:559–75; Maikel Kuijpers, *An Archaeology of Skill: Metalworking Skill and Material Specialization in Early Bronze Central Europe* (London, 2018).

14. For example, Timothy J. Earle, J. Ling, C. Uhnér, Z. Stos-Gale, and L. Melheim, "The Political Economy and Metal Trade in Bronze Age Europe: Understanding Regional Variability in Terms of Comparative Advantages and Articulations," *European Journal of Archaeology*, 2015, *18*:633–57; Paul Budd and Timothy Taylor, "The Faerie Smith Meets the Bronze Industry: Magic versus Science in the Interpretation of Prehistoric Metal-Making," *World Archaeology*, 1995, *27*:133–43; Helle Vandkilde, "Metallurgy, Inequality and Globalization in the Bronze Age: Discussant's Commentary on the Papers in the Metallurgy Session," in *Der Griff nach den Sternen: Wie Europas Eliten zu Macht und Reichtum kamen. Internationales Symposium in Halle (Saale) 16.–21. Februar 2005*, ed. H. Meller and F. Bertemes (Halle, 2010), 903–10; Kristian Kristiansen, "From Stone to Bronze: The Evolution of Social Complexity in Northern Europe, 2300–1200 BC," in *Specialization, Exchange, and Complex Societies*, ed. E. M. Brumfiel and T. Earle (Cambridge, 1987), 30–51. For a critique, see Maikel H. G. Kuijpers, "The Sound of Fire, Taste of Copper, Feel of Bronze, and Colours of the Cast: Sensory Aspects of Metalworking Technology," in *Embodied Knowledge: Historical Perspectives on Belief and Technology*, ed. M. L. S. Sørensen and K. Rebay-Salisbury (Oxford, 2013), 137–50.

15. Gordon V. Childe, *The Bronze Age* (Cambridge, 1930), 2–3.

16. David Killick, "The Awkward Adolescence of Archaeological Science," *Journal of Archaeological Science*, 2015, *56*: 242–47, at 298; Christopher P. Thornton, "Archaeometallurgy: Evidence of a Paradigm Shift?" in *Metals and Societies: Studies in Honour of Barbara S. Ottaway*, ed. B. W. Roberts and T. L. Kienlin (Bonn, 2009), 25–33, at 26.

17. For a more detailed and nuanced discussion on this and the underlying philosophical positions, see Marcia-Anne Dobres, "Archaeologies of Technology," *Cambridge Journal of Economics*, 2010, *34*:103–14; A. Jones, "Archaeometry and Materiality: Materials-Based Analysis in Theory and Practice," *Archaeometry*, 2004, *46*:327–38; David Killick, "Social Constructionist Approaches to the Study of Technology," *World Archaeology*, 2004, *36*:571–78; Kuijpers, *An Archaeology of Skill* (cit. n.13); A. M. Pollard and Peter Bray, "A Bicycle Made for Two? The Integration of Scientific Techniques into Archaeological Interpretation," *Annual Review of Anthropology*, 2007, *36*:245–59.

of artifacts and materials; the latter is contextual and takes people as its starting point. Typically, these frameworks have little or no overlap in terms of methodologies, focus, and understandings. They are different ways of doing archaeology. This gap between the social archaeologists' interpretations of metalworking technology and the material scientists' body of factual data has long been recognized.[18] There have been pleas to combine the two, but *how* to do so remains the central issue.

Materials, Skills, Cognition

Technical skills exist where material and maker meet. They appear in a sensorial interplay with the qualities and constraints of a material. To understand what skill brings about, it is important to explore the relationship between cognitive knowledge and skilled practice. How does engagement with a material, through the senses, lead to knowledge about that material?

In addition to the two frameworks mentioned in the previous section, I propose adding a third one: the psychophysical framework. This framework operates at the intersection of cognition and materiality. Lacking other more precise tools, it is through the body that prehistoric metalworkers would have learned and categorized their materials.

A sensorial categorization of material is distinct from the scientific one but not separate from it. After all, the qualities and behavior of a material are a sensorial reading of the properties from which they stem. Hence, I am *not* arguing that scientific analyses are incapable of shedding light on questions about prehistoric craft and skill. But one needs to look at them where, quite literally, they make sense.

To operationalize this perspective, I make use of *perceptive categories*. This methodology works with data provided by material sciences, but the thresholds with regard to the categorization and analysis of this data are based on the human senses and thus on metalworking as a craft. Perceptive categories emphasize the qualities, behavior, and performance of materials that are recognizable and relevant to craftspeople and attempts to associate these with the properties and processes for which scientific measurements are available.

In short, this method aims to organize the data into categories attuned to the aspects of the materials that matter to craftspeople. This is a pragmatic attempt to work with the data we have in an empirical manner, without violating either our epistemology (scientific knowledge) or the prehistoric epistemology we are trying to uncover (craft knowledge).

18. Pollard and Bray, "A Bicycle Made for Two?"; Jones, "Archaeometry and Materiality"; Mark Pearce, "Archaeology and Archaeometallurgy: Some Unresolved Areas in the Interpretation of Analytical Data," *STAR: Science & Technology of Archaeological Research*, 2016, *2*:46–53; Christopher P. Thornton, "Archaeometallurgy: Evidence of a Paradigm Shift?" in *Metals and Societies: Studies in Honour of Barbara S. Ottaway*, ed. B. W. Roberts and T. L. Kienlin (Bonn, 2009), 25–33.

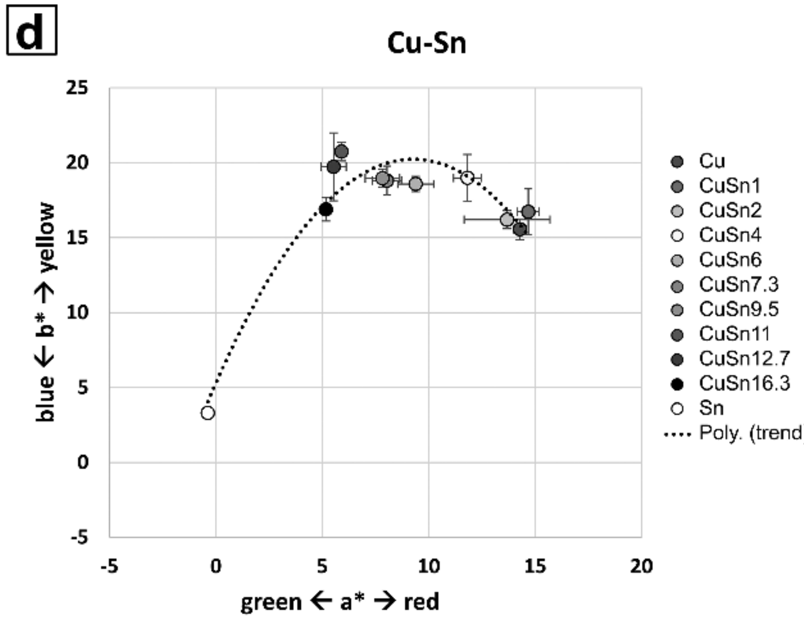

FIG. 1 The scientific way in which color difference is documented: CIELAB coordinates with error bars of a copper-tin alloy. This is accurate but does not tell us which differences are perceivable (reworked from Mödlinger et al., "Quantitative Comparisons").

Translating properties into perceptive categories does two things. First, it forces the theorists on materiality to define and pin down what is relevant about the material in question and, importantly, how this relates to underlying material properties. Second, it forces the material scientist to step away from too detailed a measurement and ask where the threshold is after which the measured quantity becomes a perceivable quality of the material. A brief example on the color of metal should suffice to illustrate this idea.

Color Is Composition

The amount of tin in a bronze is a property that the material scientist can measure in percentages; for the metalworker, however, it equals the quality of color (figs. 1 and 2). Color plays an important role because it provides the metalworker with a perceivable quality of the material that allows for differentiating between copper-compositions.[19] Historical sources

19. Svend Hansen, "Innovative Metals: Copper, Gold and Silver in the Black Sea Region and the Carpathian Basin During the 5th and 4th Millennium BC," in *Metal Matters: Innovative Technologies and Social Change in Prehistory and Antiquity*, ed. S. Burmeister, S. Hansen, M. Kunst, and N. M. Müller-Scheessel (Rahden/Westfalen, 2013), 137–70; Tobias L. Kienlin, Ewald Bischoff, and Horst Opielka, "Copper and Bronze during the Eneolithic and Early Bronze Age: A Metallographic Examination of

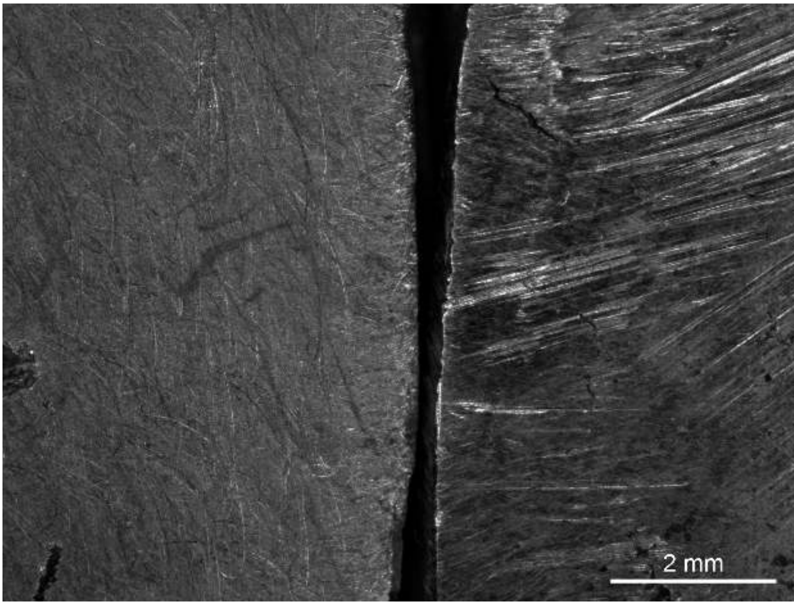

FIG. 2 Why color matters. On the left a "pure" copper (>98% Cu), on the right the Bronze Age standard copper-tin alloy (approx. 90% Cu and 10% Sn). An attentive metalworker will already notice color differences from about 2 percent tin, but only at 5 percent does it become very pronounced, altering the behavior of the metal and making it noticeably harder when worked (Kuijpers, *An Archaeology of Skill*, 107–8).

leave little doubt that color was a key indicator of specific metals and their purity.[20] This, therefore, relates to a prescientific understanding of compositional differences.

The recognition that color must have been important in the development of metalworking skills led some research to quantify the relationship between composition and color.[21] This is an interesting and worthwhile development because it draws materiality into the domain of material sci-

Axes from the Northalpine Region," *Archaeometry*, 2006, *48*:453–68; Marianne Mödlinger, Maikel H. G. Kuijpers, D. Braekmans, and D. Berger, "Quantitative Comparisons of the Color of CuAs, CuSn, CuNi, and CuSb Alloys," *Journal of Archaeological Science*, 2017, *88*:14–23; Mark Pearce, *Bright Blades and Red Metal: Essays on North Italian Prehistoric Metalwork* (London, 2007).

20. Georgius Agricola, *De Re Metallica* (New York, 1950); André Guettier, *A Practical Guide for the Manufacture of Metallic Alloys: Comprising Their Chemical and Physical Properties, with Their Preparation, Composition, and Uses* (Philadelphia, 1872).

21. Mödlinger et al., "Quantitative Comparisons"; Radivojević et al., "The Provenance, Use, and Circulation of Metals in the European Bronze Age"; Miljana Radivojević, J. Pendić, A. Srejić, M. Korać, C. Davey, A. Benzonelli, M. Martinón-Torres, N. Jovanović, and Ž. Kamberović, "Experimental Design of the Cu-As-Sn Ternary Colour Diagram," *Journal of Archaeological Science*, 2018, 90:106–19.

ences. At the same time, if we merely shift scientific analysis from precisely and accurately detailing composition to accurately quantifying color, little progress is made, because the problem is exactly in this accuracy. Paradoxically, we know too much, in too much detail.

To the scientist this accuracy and precision matters, whereas a craftsperson approximates. This is why we need the perceptive categories. Bringing into focus the properties that are perceivable, these categories are scientifically less accurate but meaningful and relevant to metalworkers. At the same time, these categories are substantiated through scientific measurements and as such are a helpful analytical tool through which scientific techniques can be integrated into archaeological interpretation.[22] This might be thought of as a quantitative phenomenology.[23]

In my work I argue for six different perceptive categories of copper-composition that might have been relevant to metalworkers of Early Bronze Age Europe. With the help of a *chaîne opératoire* that incorporates these categories, it is demonstrated that indeed these were recognized and worked differently from one another.

For instance, whereas modern science distinguishes antimony, arsenic, silver, and nickel, in the Bronze Age these elements were likely understood as one and the same "thing" corrupting the normal qualities of copper.[24] Copper containing a combination of these elements in excess of 7 percent (categorized as type V: white copper) was worked distinctly differently from "pure" copper (type I: red copper) or typical tin-bronze (type III: yellow copper).[25]

Confirming the existence of such categorization in prehistory also—importantly—gives us insight into what prehistoric knowledge looked like.

22. Pollard and Bray, "A Bicycle Made for Two?"

23. The phenomenological approach in archaeology was a welcome change of perspective to contrast the prioritization of the role of the mind in human cognition. See Joanna Brück, "Experiencing the Past? The Development of a Phenomenological Archaeology in British Prehistory," *Archaeological Dialogues*, 2005, *12*:45–72, at 45. However, this approach typically involves some kind of bodily experiments in which the researcher acts as the main methodological tool through which interpretations are made, e.g., Yannis Hamilakis, *Archaeology and the Senses: Human Experience, Memory, and Affect* (New York, 2013); Christopher Y. Tilley, *The Materiality of Stone: Explorations in Landscape Phenomenology* (Oxford, 2004). Critics have rightfully pointed out the problematic anecdotal and speculative nature of this kind of research: Brück, "Experiencing the Past?"; Kuijpers, "The Sound of Fire"; Andrew Fleming, "Post-processual Landscape Archaeology: A Critique," *Cambridge Archaeological Journal*, 2006, *16*:267–80. Perceptive categories differ in this respect because of the underlying quantification and their trialability.

24. Cf. "cadmia" in Agricola, *De Re Metallica*, 112–13.

25. Maikel Kuijpers, "A Sensory Update to the Chaîne Opératoire in Order to Study Skill: Perceptive Categories for Copper-Compositions in Archaeometallurgy," *Journal of Archaeological Method and Theory*, 2017, *25*:863–91; Kuijpers, *An Archaeology of Skill*.

Making Is Knowing

There is no need to understand *why* there is an association between composition and color to be able to recognize and act upon it. This material engagement is one of the ways through which propositional knowledge can be produced, however. Seeing and experiencing differences in the color of copper-compositions led the prehistoric metalworker to a basic cognitive understanding of composition. This knowledge made alloying possible, or even *thinkable*.

As of late, and partly under the influence of the practical and material turn, researchers from different disciplines are breaking down the distinction between craft skills and scientific knowledge; thinking and doing; the hand and the head; the mind and the body.[26] The deeply entangled nature of humans, things, and materials is increasingly recognized and stressed. These entanglements shape who we are and what we value.[27] We not only live in a material world, we have "material minds."[28] Experiencing material realities helps construct cognition. This is a core idea held by a group of researchers who argue that cognition extends beyond the brain.[29] With regard to the history of science and technology, in particular, Pamela H. Smith's work is concerned with how practical skills and the articulation of this knowledge are related, which she has dubbed "vernacular science."[30]

Smith convincingly argues that in the earliest phases of the Scientific Revolution, making and scientific knowing were not separate. My research

26. On knowledge, see Helen Tilley, "Global Histories, Vernacular Science, and African Genealogies; or, Is the History of Science Ready for the World?" *Isis*, 2010, *101*: 110–19; Pamela H. Smith, Amy R. W. Meyers, and Harold J. Cook, eds., *Ways of Making and Knowing: The Material Culture of Empirical Knowledge* (Ann Arbor, 2014). On thinking and doing, see Matthew Crawford, *Shop Class as Soulcraft: An Inquiry into the Value of Work* (New York, 2009); Richard Sennett, *The Craftsman* (London, 2009). On hand and head, see Trevor H. J. Marchand, *Making Knowledge: Explorations of the Indissoluble Relation between Mind, Body and Environment* (Malden, Mass., 2010); Frank R. Wilson, *The Hand: How Its Use Shapes the Brain, Language, and Human Culture* (New York, 1999). On mind and body, see Tim Ingold, *The Perception of the Environment: Essays in Livelihood, Dwelling and Skill* (London, 2000).

27. Ian Hodder, *Entangled: An Archaeology of the Relationships between Humans and Things* (Malden, Mass., 2012); Ian Morris, *Foragers, Farmers, and Fossil Fuels: How Human Values Evolve* (Princeton, 2015).

28. Nicole Boivin, *Material Cultures, Material Minds: The Impact of Things on Human Thought, Society, and Evolution* (Cambridge, 2008).

29. Andy Clark, *Supersizing the Mind: Embodiment, Action, and Cognitive Extension* (Oxford, 2008); Lambros Malafouris, *How Things Shape the Mind: A Theory of Material Engagement* (Cambridge, Mass., 2013); Colin Renfrew, *Prehistory: The Making of the Human Mind* (London, 2007); Mark Rowlands, *The New Science of the Mind: From Extended Mind to Embodied Phenomenology* (Cambridge, Mass., 2013).

30. Pamela H. Smith, "Making as Knowing: Craft as a Natural Philosophy," in *Ways of Making and Knowing: The Material Culture of Empirical Knowledge*, ed. P. H. Smith, A. R. W. Meyers, and H. J. Cook (Ann Arbor, 2014), 17–47.

concerns a period in a far deeper history where any separation between science, craft, technology, or art becomes untenable. These are modern categorizations that help shape our thoughts and disciplines. In this respect they can be useful analytical tools, when explicitly defined, but we should not theorize them into existence where they were not.[31]

Archaeology clearly shows that people first got things to work, long before they were concerned with a systematic articulation or written account of why and how they worked. In Needham's favorite metaphor, rivers of knowledge flowed into the sea of modern ecumenical science. I will complicate this metaphor. From an undifferentiated sea of contextual experiential knowledge, science and technology are but two specific channels through which this knowledge can be directed.

Conclusion

In the history of science and technology the question of whether and how practice and knowledge or craft and science are related is an interesting theoretical and analytical issue.[32] In archaeology it is also a very practical problem, because it is through science that knowledge about prehistoric crafts is generated. Rather than seeing an opposition between craft and science, which inevitably seems to result in scholars becoming entrenched on either side of this dichotomy, I looked for their convergence. The material thinking of craftspeople and analytical thinking of scientists lead to a different choice of categorization and metaphors, but both are equally dependent on the physical properties of material that anchor the produced knowledge. These two epistemologies must therefore be compatible with each other. Science and craftspeople are not describing different material realities; they are simply describing reality differently.

But my suggestion goes further than this, and I would like to end with a challenging hypothesis: knowledge is partly based in the material and therefore might belong to the material—as a kind of heritage of materials. Depending on the heuristic used—science, craft, or art—this knowledge is colored differently.

How then should we phrase the Needham question nowadays? In such a way that it does not implicitly assume a hierarchical top position for sci-

31. For instance, where do we categorize basketry? "The basket is an emergent artefact, both form and frame; product and technology; artefact and tool"; Stephanie Bunn, "Weaving Solutions to Woven Problems," in *Craftwork as Problem Solving: Ethnographic Studies of Design and Making*, ed. T. H. J. Marchand (London/New York, 2016), 133–49, at 138. One can also employ the categorization usefully, however. See Francesca Bray, "Science, Technique, Technology: Passages between Matter and Knowledge in Imperial Chinese Agriculture," *British Journal for the History of Science*, 2008, *41*:319–44.

32. E.g., Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago, 1995).

ence and is open to the full potential of the different knowledge identities. Needham was ahead of his time when he blurred the boundaries between technology and science, although it is doubtful that he did so for an analytical purpose. His blurring was out of necessity and, importantly, retained an understanding of technology as applied science. Despite his utopian vision of an ecumenical science, Needham was well aware of the threat of science achieving a supremacy over all other modes of human understanding—and he was not having it.[33]

In his obituary of Needham in this journal, Multhauf calls him a "mason," which I think is quite fitting.[34] Not only was his synthetic thinking constructive in nature: Needham worked like a craftsman. He had purpose yet let himself be guided by his materials.

Let us at least take this away from his work. There are more ways than one of perceiving the materials and their potential. Importantly, the boundaries between them are permeable, and so our disciplines ought to be. The work to be done is on a history of knowledge, in which the history of science is but a regional, specific subfield.[35] But perhaps we should start by asking, *What do we consider valuable knowledge, and why?*

33. Joseph Needham, *Moulds of Understanding: A Pattern of Natural Philosophy* (London, 1976), in passim.

34. Robert P. Multhauf, "Joseph Needham (1900–1995)," *Technology and Culture*, 1996, *37*:880–91.

35. Cf. Lorraine Daston, "The History of Science and the History of Knowledge," *KNOW: A Journal on the Formation of Knowledge*, 2017, *1*:131–54.