Historians in the Laboratory: Reconstruction of Renaissance Art and Technology in the Making and Knowing Project

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Detail from the Making and Knowing Laboratory, the paper test (*plate 8*).

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The Inadequacy of Words

In the sixteenth and seventeenth centuries, European scholars began to search for a new kind of knowledge, what Francis Bacon (1561–1626) in 1620 would call a 'New Philosophy; or Active Science' (*The Great Instauration*, 1620), and what we have come to see as the beginnings of the modern natural sciences. These scholars sought to engage with the things of nature, in addition to the words of texts, and, as they looked about for models of this new kind of enquiry, they took up the case history used by their medical colleagues. They also looked to the methods of history, for history involved gathering observations and experiences about the human world, just as the new type of investigation these scholars sought would observe and collect experiences of the natural realm. They began to call what they did 'natural history'.[1] These scholars also looked to the handwork of craftspeople and their ability to manipulate natural materials in order to produce valuable products. Where these newly self-described 'natural historians' and 'experimental philosophers' could read the texts of their medical and historian colleagues, they generally had no such familiar entry point into handwork, for craftspeople produced things, and only rarely recorded their work in words and texts that the scholars could read.[2] As Francis Bacon complained in the *Novum Organum*, 'experience is illiterate'. Of course, craftspeople were not illiterate, but were fluent, rather, in a different kind of language and knowledge, one that posed problems for sixteenth-century scholars, and continues to make life difficult for the historians who study them. In the following essay, we suggest that one means for overcoming this problem is to bring historians and natural scientists back into conversation with each other, as they were in the sixteenth century when exploration of the human world provided a model for the just emerging study of the natural realm.

Between 1400 and 1700, European craftspeople similarly found words to be inadequate: they paradoxically declared *in writing* that writing was inadequate to convey their skills, and that book learning was inferior to bodily experience. Benvenuto Cellini (1500–71) in *Two Treatises on Goldsmithing and Sculpture*, wrote, 'How careful you have to be with this cannot be told in words alone – you'll have to learn that by experience.'[3] Bernard Palissy (*c.* 1510–90), who created extraordinary ceramics in France declared:

> Even if I used a thousand reams of paper to write down all the accidents that have happened to me in learning this art, you must be assured that, however

> good a brain you may have, you will still make a thousand mistakes, which cannot be learned from writings, and even if you had them in writing, you would not believe them until practice has given you a thousand afflictions.[4]

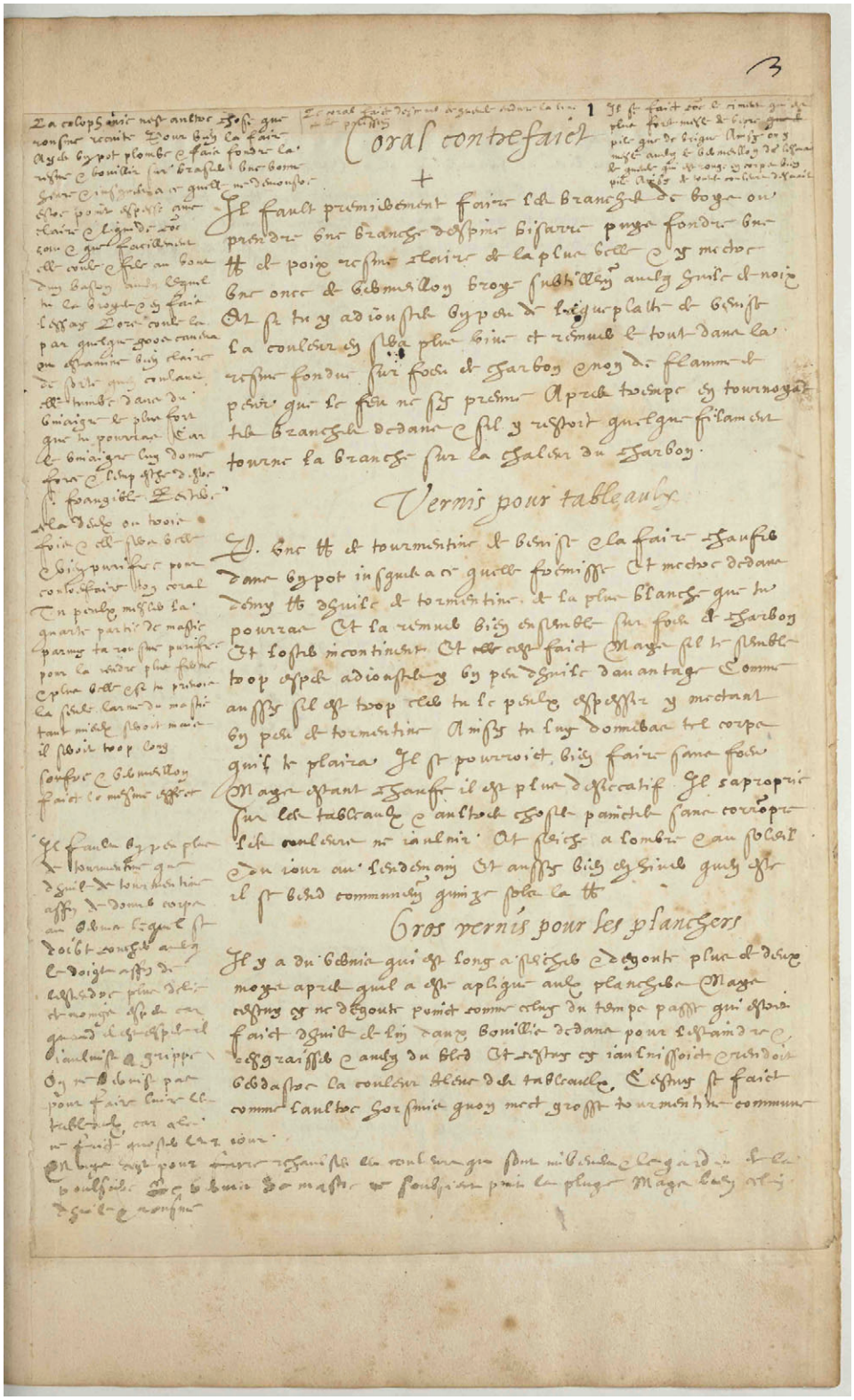
In his defence of craftsmen's knowledge, the religious, medical, and intellectual reformer, Theophrastus von Hohenheim, called Paracelsus (1493–1541), declared in writing that writings teach nothing: 'For who could be taught the knowledge of experience from paper? Since paper has the property to produce lazy and sleepy people, who are haughty and learn to persuade themselves and to fly without wings. . . . Therefore the most fundamental thing is to hasten to experience.'[5]

These statements form part of a remarkable development in European history, commencing around 1400, during which craftspeople and practitioners, used to looking, learning, and practising on the shop floor, suddenly transformed their lived experience and embodied – often tacit – knowledge into writing and compiled it into texts. Many well-known artists, such as Cellini and Leonardo da Vinci (1452–1519), wrote about their techniques, but many more lesser-known artisans, including gunpowder makers, fortification experts, and navigators, who previously had been happy to live out their lives without recording their experiences and knowledge, and creating and producing in relative obscurity, suddenly began to write. A flood of technical writing followed with the advent of printing in the 1460s, as recipe collections and technical treatises became some of the biggest bestsellers. Works in the vernacular appeared on distillation, mining, assaying and metalworking, and then there appeared 'books of secrets', which sound esoteric, but actually, in effect, were collections of all kinds of technical recipes, which, while practical and useful, also hinted at the tacit dimension and initiation process of much technical knowledge. The pseudonymous Alessio Piemontese's *Secrets*, a true early modern bestseller, is the exemplar of such texts, published and republished in varying editions from 1555. This boom in what we have come to call 'how-to' books continued into the eighteenth century.[6] Arguably, this how-to literature fostered on the part of its readers new attitudes to the creative process and to technical ability.

Writing Down Art

Why did craftspeople begin to write down their knowledge, especially in texts that declare written accounts to be useless? Writing down techniques is not an easy thing to do, as it is enormously inefficient, and steals time away from actually making a livelihood. Moreover, craftspeople did not (and still do not) learn skills from books, or even sometimes by language at all, but by experience, working alongside skilled practitioners, observing and imitating. The knowledge they gained was known in their bodies, and written descriptions could only point to bodily activity, but could not teach it or even describe it fully. In addition, craft work involved unpredictable qualities of materials, always-changing workshop conditions, and rapidly transforming matter, all of which the craftsperson had to respond to in real time. Little of this could be captured or codified in writing, for a text is just not an optimal means for conveying technique. Interestingly, this problem also plagues the natural sciences today, and has led to innovations such as the *Journal of Visualized Experiments*, which is 'devoted to publishing scientific research in a visual format to help researchers overcome … poor reproducibility, and the time and labor-intensive nature of learning new experimental techniques'.[7]

What should historians make of this how-to literature in early modern Europe? Why did practitioners write it down? Is it really a record of practice? Who is it for? Why did it sell so well? Is it really meant for use, or for teaching 'how to'?[8] How might historians make use of this genre – often simply compilations of technical recipes – as historical evidence, and what sort of evidence does



1 BnF Ms. Fr. 640, f. 3r, probably late sixteenth century. Photo: Bibliothèque nationale de France, Paris. ['Coral contrefaict' (imitation coral) is the first recipe in the text block. Also included on this page are two recipes for varnish.]

it supply? These writings would seem to provide evidence to help understand materials and techniques employed by artists in the past, and they have been used in this way by conservators and some art historians, but historians have also determined that such technical literature does not always reflect practices current at the time of writing.[9] What then is the nature and the status of the evidence such literature provides to a historian? To analyse this complex of issues, and to obtain a better sense of the purpose and ambitions of this literature, I began a close examination of a sixteenth-century technical manuscript mostly in French held by the Bibliothèque nationale in Paris, Ms. Fr. 640 (*plate 1*).[10] This manuscript exists in a fair copy, almost exclusively in a single hand, and has been well preserved since the seventeenth century, when it entered the King's Library as part of the donation of their library by the Dukes de Béthune.[11] The manuscript's 170 folios consist of a collection of mainly technical recipes in no apparent order for objects that might have formed the contents of a *Kunstkammer* (art chamber or cabinet), a type of collection brought together by European elites in the fifteenth through seventeenth centuries.[12] The manuscript's recipes would have pleased such collectors who delighted in objects that demonstrated the interplay of nature's artifice with that of the human hand, for they contain instructions for the draughtsman, for pigment-making, wood- and metal-colouring, imitation gem production, tree-grafting, land-surveying, a practice of taxidermy to manufacture monstrous composite animals (kittens and bats, among others), making papier mâché masks, and much more. In some respects, this manuscript resembles a 'book of secrets' such as that published in Italian under Alessio Piemontese's name in 1555. Like BnF Ms. Fr. 640, such books of secrets contained recipes for materials and objects ranging from perfumes, pigments, medicines, and cosmetics to small sculpture and portrait medals, as well as techniques for house- and landholders.[13] While Ms. Fr. 640 contains recipes for all such things, the largest numbers of recipes concentrate on techniques of mouldmaking, metal casting, and colour-making (pigments, dyes, varnishes, artificial gems, and colouring woods and metals).

The author of this intriguing manuscript may have been based in Languedoc, as he[14] mentions towns of this area, particularly Toulouse. Although not obviously the master of any trade, he clearly possessed firsthand knowledge of techniques for pigment preparation, painting, casting, and jewellery making, and awareness of many other now obscure European working practices, apparently through travel or exchange in the workshop. It would appear that the author-practitioner had plans to transform the manuscript into a book, presumably for publication. He reads Latin, albeit faultily, and appears to plan to incorporate Latin tags and allusions to ancient authors in his manuscript. This anonymous author-practitioner is a vocal and self-reflective witness to his culture, and his text offers insight into how natural materials and art objects were made, collected, appreciated, and circulated in a period of burgeoning production and consumption of material goods. Because he includes so much information about animals and natural materials, the manuscript also provides a rare view into attitudes to nature at the dawn of the 'new experimental philosophy'.

While the manuscript writings of many well-known artists, including those of Cennino Cennini (*c.* 1360–before 1427), Lorenzo Ghiberti (1378–1455), Leonardo da Vinci, and Cellini, began to be published in the nineteenth century, very few anonymous manuscript sources similar to Ms. Fr. 640 have received attention. Two recent exceptions are the manuscript compilation of illumination

techniques stretching over three centuries from the Monastery of Tegernsee, the *Liber illuministarum* (*c.* 1200–1500), and the anonymous Montpellier *Liber diversarum arcium* (*c.* 1300).[15] These treatises lack the immediacy, self-reflexivity, and processual character of Ms. Fr. 640. In view of the proliferation of books of secrets during the early modern period, the singular nature of Ms. Fr. 640 renders it all the more interesting as a primary source: it differs from most other such collections of techniques in its apparent lack of formulaic recipes, its constant reference to the writer's own experiences, its extensive observations of animal behaviour, and its illustrations. The margins of the instructions are overflowing with the practitioner's comments on his trials of various technical processes, thus the manuscript forms much more than a prescription of procedure; it is also a rich record of workshop processes and attitudes to the material world.

In spite of the obviously fascinating nature and density of information to be gained from this manuscript, we found it difficult to decipher – not by reason of the script, which is fairly regular and legible, but because of its apparently unordered organization, and the obscurity of its contents – what *are* these materials and techniques? While it is possible to determine whether the materials and processes had a relationship to contemporaneous techniques described by other technical writings of the period, including Cellini, Piemontese (probably the scholar Girolamo Ruscelli), and Vannoccio Biringuccio (1480–*c.* 1539)[16], it was not immediately obvious whether the apparently firsthand accounts of work were actually so. Perhaps they were just the fruit of years of recipe collecting, with concern neither for the actual technical procedures nor for the production of things. The question of the status of a recipe compilation as evidence of historical practice arose once more.

Reconstruction as Method

Reconstruction of the recipes in the manuscript appeared promising as a means to begin to answer some of the questions that recipe compilations present to the historian. It could help to understand the materials and techniques in this manuscript, so difficult to draw out by reading alone, and whether these recipes were intended to be efficacious, that is, was the author-practitioner actually engaged in working through the recipes, and thus could the manuscript itself be read as a record of practice? We hoped that grappling with the recipes might allow a glimpse into the mental world of the practitioner to gain a stronger sense of a Renaissance understanding of materials and of the ability to transform them. Perhaps it might also be possible to gain a clue to the possible motivations for writing down technique. Finally, whatever the insights into the manuscript, this mode of research would help think through the methodological implications of using reconstruction as a source of evidence for historians.

While techniques of reconstruction are familiar to museum scholars, conservators, and archaeologists, they are less well known, and less interesting, to general historians and many art historians. My own apprenticeship began with classes on historical techniques of painting and metal working. After an all too brief apprenticeship in courses on historical techniques, I began working with Tonny Beentjes, a practising silversmith and Programme Leader of Metals Conservation at the University of Amsterdam, in order to reconstruct techniques of casting from life by trying the very detailed instructions for life-casting techniques in Ms. Fr. 640. In conjunction with the conservation staff, including Joosje van Bennekom, of the Rijksmuseum, Amsterdam, we were able to compare the instructions in the

French manuscript with the objects of the master goldsmith of Nuremberg, Wenzel Jamnitzer (1510–85), famed for his remarkable life-casting, including his metre tall table centrepiece, held by the Rijksmuseum (*plate* 2).[17]

2 Wenzel Jamnitzer, *Table Centerpiece*, 1549. Silver, cast, chased, and stamped, etched, gilded, and painted, height 100 cm. Rijksmuseum: Amsterdam. Photo: Rijksmuseum. [Encrusted with small animals and plants cast from life, this centerpiece is a paean to Terra Mater and her fertility. Plants and small reptiles cluster at the base. Mother Earth supports a basin, with life-cast snakes and lizards around the rim. The floor of the basin is decorated with cornucopias and moresques, while the egg-shaped vase holds plants and flowers, also cast from life.]

3 Circle of Wenzel Jamnitzer, *Lizard Cast from Life*, c. 1540–50. Silver, 7 × 4.1 cm. Nuremburg: Germanisches Nationalmuseum. Photo: Pamela H. Smith.

The stunningly lifelike objects produced by Renaissance life-casting techniques encouraged conversations in early modern collections about the interplay of human art and nature, and about the multiple valences possessed by the creatures used for life-casting: these animals were often inhabitants of more than one elemental zone, including frogs, toads, salamanders, lizards, crabs, crayfish and some snakes, which inhabited both earth and water; insects and birds were denizens of earth, air, and, in the case of insects, were seen to belong to fire as well, as I have discussed elsewhere.[18] The first stage of our investigation was to examine life-cast objects in museums for the traces of techniques used in Ms. Fr. 640, and then to reconstruct the techniques of the practitioner-author of our manuscript. Where he engaged in a laborious process of translating his making and doing into words and writing, we reverse engineered his words into processes and products. This reverse engineering necessitated conventional textual research, object-based research, and the hands-on research of reconstruction. We started by reconstructing the life-casting of lizards (*plate* 3). We did not, however, re-enact the catching, feeding, and killing of these animals described

4 The Making and Knowing Laboratory, life-cast rose, the result of experiments by Giulia Chiostrini and Jeffrey Palframan, 2015. Photo: The Making and Knowing Team, Columbia University.

in vivid detail in the manuscript, such as the technique of catching a lizard by suspending a net with a slip knot from a stick, then whistling while dropping it around the lizard's head – a method that herpetologists still use today.[19] Our first lizard reconstruction was quite flawed, but with experience, our castings improved (*plate* 4), and we were able to draw out much detailed technical information from the manuscript about materials and procedures.[20] Our reconstructions gave many kinds of insight into the manuscript: one of the most basic – and most important – for beginning to understand the intentions of the manuscript was that we gained certainty that the manuscript did indeed accurately describe the techniques and materials by which life-casting was carried out in the sixteenth century. It clarified a whole series of techniques, and demonstrated that various (and sometimes implausible) materials could be employed to produce the intended end products of the recipes. The insights I as a text-centric scholar gained into the nature of experience and experiential knowledge, although perhaps familiar to craftspeople and artists even today, were invaluable and would not have been possible simply by reading the manuscript. Straightforward reading of the manuscript was in any case not really possible because it is not a linear text, nor, despite its unusual detail, does it usually provide enough information for a reader to follow the procedures as one does in most modern cookbooks. As I have noted before,[21] understanding the text cannot actually be separated from trying the methods recorded in it, for the manuscript's author-practitioner set down his text at various intervals in a fair copy, followed by more experimentation, which gave rise to failures and new ideas, followed by further observations and trials, all recorded in increasingly cramped script in the margins, and, indeed, in any available space in the manuscript (sometimes, but not always, indicated by insertion marks). It appears that the *composition* of the manuscript itself could not be divorced from actually performing the actions. The text enacts the trying again and again of the author-practitioner, and the essential need to proceed in gaining an understanding of materials and processes by what we would call the method of 'experimentation'. The recipes in the manuscript necessitate imitation and re-enactment in order to be comprehensible. Indeed, it became clear to us that 'reading' the text for understanding in fact meant reconstructing the actions described in it.

Recipes and Emergent Knowledge

These experiences led me to conclude that the modest form of a technical recipe actually forms an efficient vehicle for conveying the nature of practical knowledge in the Renaissance. By their usually anonymous form, recipes assert the collective and cumulative nature of practical knowledge-making.[22] Like other written forms

of practical knowledge, recipes can point to bodily action, but obviously cannot accomplish that action, nor provide for every circumstance which might bring about necessary variations in procedure. Especially in the early modern period, recipes were often listed in series, setting out several slightly varying instructions for the same process or object, often simply labelled 'another way'. The recipes thus formed an invitation to action, and, by their serial format, replicated the necessity of repeated hands-on testing and trying in order to work through the variables and resistances of materials to bring about a successful (and replicable) result. Practical knowledge is very different from propositional knowledge, which is easy to capture in a written proof. Practical knowledge always involves emergent phenomena, and its 'proof' is brought into being in real time. A recipe, or better still, a compilation of recipes, thus indicates, in abbreviated form, the particularity, variability, and the emergent quality of material things, and of practical knowledge. Recipes, then, can effectively capture in written form – to the extent that this is possible in *writing* – this characteristic of emergence, as well as setting out a pathway for the acquisition of skill by means of which the emergent phenomena can be channelled and harnessed. Only by engaging in the practice of reconstruction – itself a form of emergent knowledge – would I have recognized this dimension of recipe compilations.

The emergent quality of reconstruction poses a problem for its status as evidence to be employed by the historian – how can a historian bring into being her own evidence and be certain of its validity? This methodological question led me to found 'The Making and Knowing Project' at Columbia University, both to examine this question by collective work, and to produce a digital critical edition and translation of Ms. Fr. 640.[23] For some time, it had seemed to me that this fascinating manuscript merited a critical edition, but I was always stymied by the inadequacy of the printed words of a conventional codex to convey the manuscript's rich contents, not to mention the multiple reconstructions that a critical edition would necessitate. The Making and Knowing Project constitutes an experiment in collaboration, crowd-sourcing, and the integration of pedagogy and original research, and involves teams of students and collective groups of participants Although it has operated for only a year, it has reaffirmed the precept that historians whose object of study is historical materials and techniques, including historians of material culture, of art, and of science in the pre-industrial period, greatly benefit from a type of literacy not generally regarded as a necessary part of their intellectual toolbox, namely, a literacy of materials and techniques. The only efficient – perhaps the sole – means of beginning to acquire this literacy is through hands-on work with materials and techniques. The reconstruction of historical techniques and objects can *begin* to provide such a training.

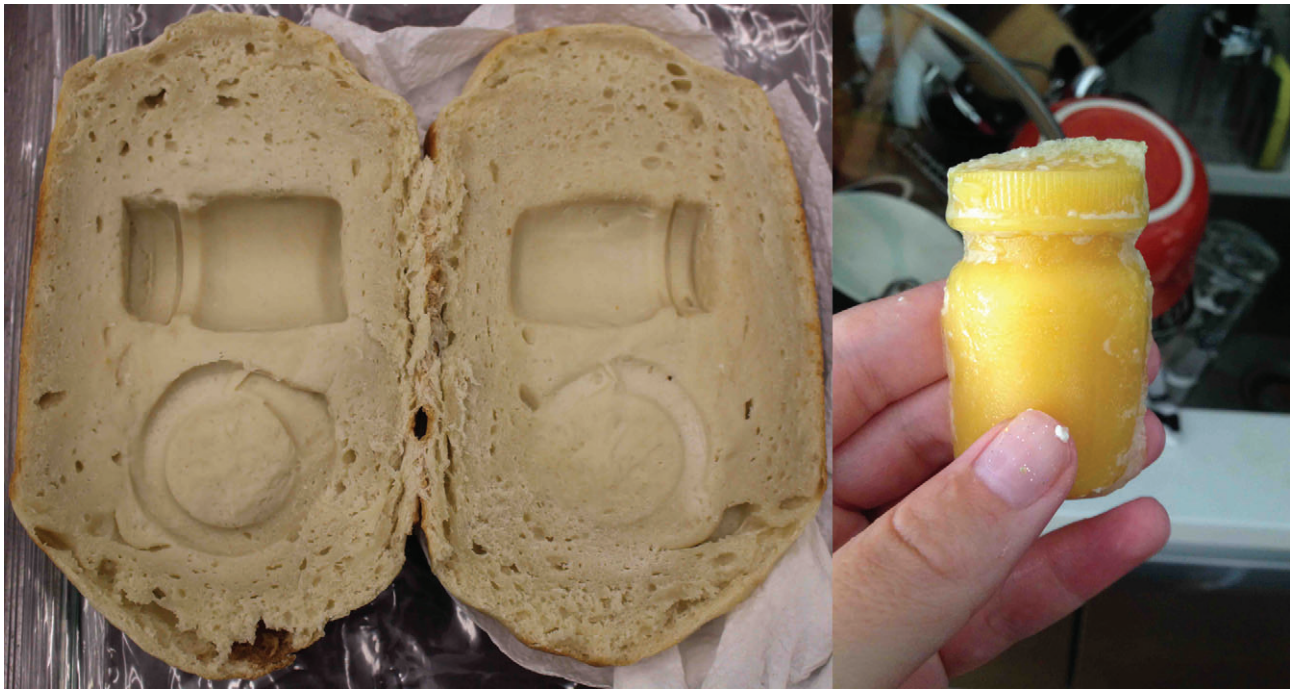
The Making and Knowing Project

The Making and Knowing project involves teams of graduate student paleographers and researchers who work throughout the course of a semester to reconstruct selected recipes from the manuscript. In 2014–15, reconstructions focused on the mouldmaking and metalworking recipes in Ms. Fr. 640;[24] in 2015–16 they will focus on colour-making recipes (including dyes, pigments, varnishes, techniques of colouring woods, metals, and making imitation stones). In order to reconstruct the recipes, conventional text, document, and object-based historical research is combined in order to begin to understand terminology and process, gain a sense of the object that is the goal of the recipe, and try to tease out a 'genealogy' for the recipe in order to make clear whether

the author-practitioner was drawing upon published (or manuscript) texts that might have been available to him. The entire project strives to engender reflection on the methodology and epistemology of reconstruction – how can we responsibly make use of reconstruction as a historical source?[25]

Reconstruction involves both subjective action, self-reporting, and the manufacture of evidence by the historian in the present, a process rife with pitfalls, thus the status and strength of its products as historical evidence must always be at the forefront of the reconstructor's consciousness. It may be useful to think of this procedure as 'historical experiments', drawing in part on the methods of the natural sciences, as Hasok Chang suggests.[26]

Reconstructions in 2014–15 included using the pith of bread ('*mie de pain*') as a mould in which to test a plaster or metal moulding patterns. Various mixtures of beeswax, tallow, and sulfur were then cast into the bread moulds (*plate* 5). In preparing and baking the bread for the moulds, we encountered the changes induced by fermentation – an important component of attitudes to nature and the body in the early modern period – as well as the changes in state that can be brought about by the mixing and tempering of the various casting materials. These exercises also provided insight into the mechanics of moulding in one- and two-piece moulds, training that continued in moulding and casting in cuttlefish bone, and, after that, in producing 'sands' and 'binders' to carry out sand casting for box moulding, and life-casting in plaster (sand and plaster casting are both regarded as varieties of 'sand' casting by the author-practitioner of Ms. Fr. 640). These reconstructions have yielded much information about the manuscript, which includes deciphering marginalia; clues to the author-practitioner's identity, as well as his level of education, knowledge and practice; his familiarity with techniques outside of his French-speaking domain; evidence of his learning new techniques or experiencing failures in his practice.[27] They have also provided insight into specific obscure techniques and materials used in the sixteenth century, such as the so-called 'incuse reverse casting' (or as the author terms it, 'Moulding a hollow on one side, and a relief on the other' ['Mouler cave d'un costé et de relief de laultre'])[28] (*plate* 6) and the material referred to as 'spalt',



5 The Making and Knowing Laboratory, bread moulding for the rapid testing of patterns, following Ms. Fr. 640, ff. 140v and 156r. Photos: The Making and Knowing Team, Columbia University. [Note detail of bottle top cast in wax.]

6 Medal pattern and convex side of medal (with casting infrastructure still attached) [left]; and pattern and concave side of medal [right]; following Ms. Fr. 640, f. 92r ('Moulding a hollow on one side and on the other a relief' [known today as 'incuse reverse casting'], the result of experiments by Michaela Groeneveld and Marianne Nuij, University of Amsterdam. Photos: Tamar Davidowitz, The Making and Knowing Project, University of Amsterdam.

'laspalt', and 'spat' by the author[29]; as well as about the nature of experiential or practical knowledge (as revealed, for example, in his use of particular terminology, such as 'impalpable', or 'attack/attach' [*s'attaquer*]).[30] The reconstructions have also given insight into daily life, such as those that dealt with mustard; the use of noisy mortars by apothecaries to attract business; a method to train a dog (involving cheese held in the armpit); millet consumption in Languedoc; and the surprising domestic production of sand for hourglasses.[31] Most interesting, perhaps, has been the insight provided by reconstruction into the author-practitioner's system of knowledge about nature and the behaviour of natural materials – his 'material imaginary'.

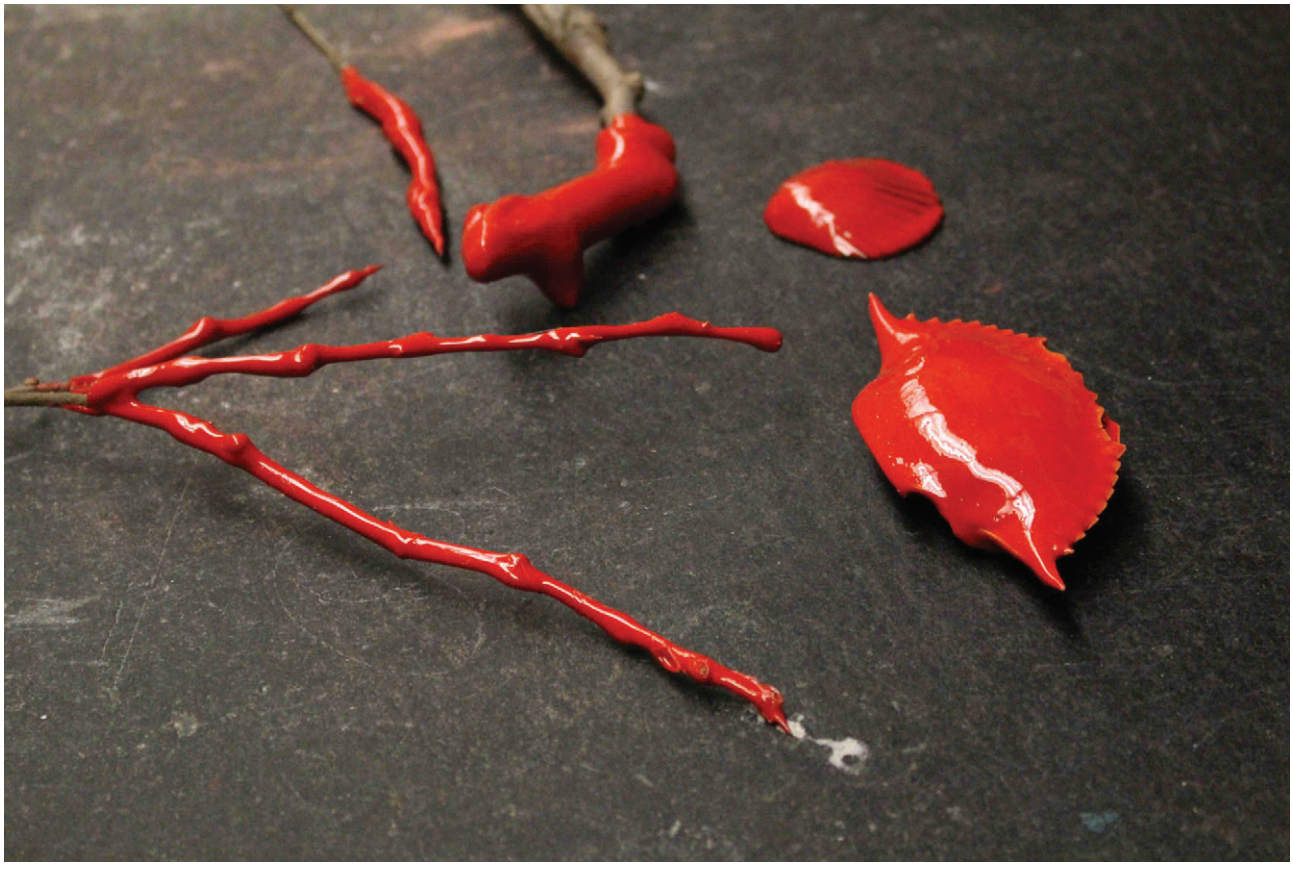
The digital publication of the critical edition itself – still in preparation – will imitate the reading experience of a codex, but with the ability to compare the four versions of the manuscript, consisting of the high-definition scans of the manuscript, the diplomatic transcription, the (lightly) normalized French transcription, and the English translation formatted as scrollable fluid text.[32] As a reader progresses through the digital edition, they will be able to open 'windows' in the text into the illustrated annotations, containing additional photographs, videos, short essays, glossary entries, and longer essays that set out provenance, context and meaning of the manuscript.[33]

The Material Imaginary of BnF Ms. Fr. 640

Many of our reconstructions of the manuscript's recipes have explicated the author-practitioner's system of natural knowledge, his 'material imaginary', and the remainder of this essay will focus on this dimension of the research. An example of this knowledge system can be found in his instructions to use rusted red iron filings as an ingredient in mould material, in order to make the mould strong. In oxidizing the iron filings, he strives for the deepest red possible and likens the colour to vermilion and cinnabar (fol. 161v). At another point, he mentions that the mould is stronger when it retains the colour of the brick dust and is red (fol. 107v). Of course, in addition to tinging the plaster mould red, the brick dust would also make the plaster mould better able to withstand the burnout and casting process.[34] By this, he might have referred to the 'strength' of blood-red colour. Blood was implicated in metalworking both metaphorically, as in the *Perseus* of Benvenuto Cellini and *Hercules*

Pomarius of Adrian de Vries, and materially in metalworking recipes, where all kinds of red substances appear among the ingredients and operations, including coral, the red pigments vermilion and cinnabar, and even blood. Red and blood are also connected to gold in these processes: red ingredients are specified in making gold pigments, and gold is used to produce red colour in glaze and glass. When taken as potable gold, or even when worn on the body, gold was seen to promote health and healing, just as the most balanced and healthful temperament – the sanguine – was associated with the humour of deep red blood in medical theory. As in other metalworking recipes, lizards, too, crop up in Ms. Fr. 640, as a reported method for turning metals a gold colour (fol. 98r). As I have treated elsewhere, red, blood, gold, and lizards were part of a knowledge system that underpinned metalworking practices and techniques, a kind of 'vernacular science' of matter and transformation, articulated by metalworkers in their works of art, their practices and their texts.[35]

Red is also important on the very first leaf of Ms. Fr. 640, where the author-practitioner has headed the page with a suggestive cross (see *plate 1*), by which he might have been following the practice of commonplace and account book writers who often began their text with a cross, under the sign of Jesus. More significantly, this page contains a recipe for imitation coral, a material that was understood both to imitate natural coral, and to explicate and replicate, in its making, the processes of growth and transformation by which coral was understood to be produced (*plate 7*).[36] The colouring ingredient of the imitation coral of Ms. Fr. 640 is vermilion, a pigment used by the painters and scribes of illuminated manuscripts, who used the mark of a cross to signify where the red pigment vermilion should be applied in the text, thereby connecting the pigment to Jesus's spilling of blood on the cross to redeem humankind.[37] Vermilion was employed to portray the blood of Jesus, such as in a Psalter, now in the British



7 The Making and Knowing Laboratory, imitation coral, following Ms. Fr. 640, f. 3r. Photo: The Making and Knowing Team, Columbia University.

8 The Making and Knowing Laboratory, the paper test. Photos: The Making and Knowing Team, Columbia University. ['To know when it (the 50–50 tin–lead alloy) is the right temperature (for casting into cuttlefish bone), dip a little piece of paper in it. If it turns black without catching fire, it is the right temperature. But if it burns and makes a fire, it is too hot'. The paper employed in this experiment is made from 50–50 hemp and cotton, heavy weight, gelatin sized, and of third quality, used in the repair and conservation of rare books, and supplied by Timothy Barrett, University of Iowa Center for the Book.]

Library, known as Egerton 1821, which opens with drops of Jesus's blood portrayed in vermilion.[38] Such practices of work were oriented to the production of goods, but they also demonstrate that materials, such as iron oxide, vermilion, and even imitation coral, functioned as epistemic things – that is, things that embodied concepts and knowledge systems (but also had real material effects in the world). In other words, craft practices functioned at levels deeper than just the operative.

The Material Imaginary: The Problem of Qualitative Descriptions and Missing Quantities

Ms. Fr. 640 contains very few quantitative measurements. It most often uses ratios (for example, one part lead to two parts tin), as seems to be common more generally in early modern technical writings, as well as other kinds of literature, such as merchant manuals and *abbaco* books that teach practical mathematical techniques for determining variables by working with ratios.[39] In our reconstructions, we soon learned to use other kinds of indicators in the manuscript in place of measured quantities, namely, descriptions of the state of the material in its final form, such as, 'Make your mixture as thin as a potato stock, or as clear as starch water, the one women use to starch' (fol. 113v), or by comparing it to the consistency of mustard (89v, 113v, 121v).[40] Temperature can be measured by feel, for example, a mould only as hot as allows a person to hold it in their hand (115v), or by the combustion point of other materials – straw (72v) – or, 'to know when it is the right temperature [for casting into cuttlefish bone], dip a little piece of paper in it. If it turns black without catching fire, it is the right temperature. But if it burns & makes a fire, it is too hot' (145r) (*plate 8*). In an early modern workshop, materials were not standard, heat was provided by wood that burned with different intensity, and environmental conditions might change with the weather; thus quantitative measures would actually have been *less* useful than qualitative descriptions of the aimed-for consistency, the appearance of the material at certain points of the process, and the testing of heat by feel (among other methods).

Qualities and Properties: Forming a Taxonomy

In general, we have found that the author-practitioner thinks through materials and their properties as he makes decisions about what to 'try' next.[41] He appears to hypothesize about the behaviour of materials on the basis of the properties they exhibit, or the processes through which he puts them, such as calcining (burning to a powdery ash), for example, to produce very fine, white 'impalpable sand' made from oyster shells, bovine bones, wheat flour, and alabaster. He makes generalizations about the properties of materials, based on their appearance, sensory look and feel (as well as smell, taste, and

sometimes sound), but most often on their usefulness for his practice. In the process, he forms a taxonomy that cuts across and organizes materials and processes, performing what, arguably, all craftspeople did as they scrounged their local environs for materials they hypothesized might be useful.[42] Early modern things were often organized according to their uses, rather than to their morphology, structure, or appearance. The contrast to today's largely morphological taxonomic classification system was brought home to us as we searched for elm roots in spring 2015 for a binder made with elm roots. Ms. Fr. 640 specifies on fol. 87v that 'Founders harvest the roots of a young elm when it is sappy, and boil it in wine, or better yet vinegar. They prepare a year's worth of it and store it in a cask.'[43] We tried this binder recipe in the fall with the easily available (amazon.com) slippery elm bark, well known for its mucilaginous properties, in spite of slippery elm being native to North America. When the ground thawed and the sap began to flow, we hunted for an authentic sixteenth-century French elm through a cross country email exchange with historical gardens' curators, learning in the process about the nostalgia for the European elm, killed off by elm disease. Finally, we decided to use a hybridized elm species that according to our informants would have been closest to the sixteenth-century elm.[44] When I asked whether this species, considered taxonomically similar today, would necessarily share the properties sought out by a sixteenth-century practitioner, or did taxonomic systems today rather operate by a different set of categories, and got the answer that in hybridization, the property of 'gooey sap from the roots would be one of the last things they were looking for',[45] I came to realize that our taxonomies for classifying species based on morphological properties determined by the visual appearance of leaf, bark, and flower, differed profoundly from the taxonomy of our author-practitioner. His system of classification was based on the properties of the material as they were expressed or manifested in the process of human manipulation, a system also found in early modern herbals, which organize plants according to their 'virtues', or properties useful to humans for healing and other processes (sometimes in an order that proceeds from 'head to toe').

States and Phases of Materials

Another dimension of the author-practitioner's material imaginary came into focus when we investigated his intensive experimentation with different types of sand ('*sable*', by which he meant the dry components of a mould) and binders (the binding medium, sometimes called a *magistra*, a term also used by other craftspeople and alchemical writers). In the metalworking recipes of the manuscript, sands and binders are employed to produce box moulding 'sand', or powder, which will take a fine impression, is cohesive enough to allow the opening of the mould, but releases the pattern easily, and is strong enough to withstand the entry of the metal into the mould. In order to create this ideal moulding matrix, dry and wet materials of various kinds are mixed carefully together to form a sand that gives 'a nice hold', but still comes 'apart easily',[46] what the lab came to refer to as the 'squeeze test' (*plate* 9).[47] In creating both the sand and the binding medium, the author-practitioner is preoccupied with transforming materials from one state to another: hard brittle oyster shells, for example, into fine powdery 'impalpable' sand.[48] Indeed, throughout the text, he is preoccupied with the native properties of materials – liquid, congealed, solid, vaporous, hard, soft, malleable, brittle, among others – and their transformation. This focus is in line with many recipes in early modern metalworking writings that attempt to 'fix' volatile materials such as mercury to make them endure the fire and become malleable or workable, and conversely to increase the plasticity of solid materials and make them capable of being moulded.

Recipes for softening hard substances, such as liquefying stone or horn in order to be able to cast them, and the related process of making brittle materials malleable, as in the transformation of iron into steel, are to be found in large numbers in such recipe collections.[49] This emphasis on changes of state indicates the nature of many of these recipes – they aimed at varying the qualities of metals by putting them through phase processes, sometimes by slow, constant, and long-term heating, such as that of an egg sitting under a broody hen, or by the heat that is given out by the slow fermentation of manure, caused by thermophilic bacteria that maintain a constant temperature. Change of state could also be brought about by dissolution in acid, or transformation through alternating heating and quenching, as in the production of steel.

The author-practitioner of Ms. Fr. 640 also induced changes of state by combining different substances to form a material with new properties, such as mixing melted wax with tallow, which produced a material more capable of being carved,[50] or mixing melted wax with different pigments, or, in a rather complicated process, passing sulfur through melted wax to bring into being a material, which, when cast, produced very smooth, milky, homogeneous surfaces, containing fine detail, with all the fine definition of sulfur casts, but less brittle, and all the malleability of wax, but without its translucency (which makes it difficult to see detail and therefore more challenging to carve fine detail).[51]

This deep preoccupation with transformations of state is developed by the author-practitioner in a series of recipes that might be called implausible, or paradoxical binders – paradoxical because, instead of mixing a dry sand and a wet binder to produce a suitable casting matrix, he used two dry materials, namely ox-bone or alabaster and rock salt, ground together to form a dry powder. This dry

9 The Making and Knowing Laboratory, the 'squeeze test' for moulding with sand in a frame, following Ms. Fr. 640, f. 118v. Photos: Emogene Cataldo and Julianna van Visco. [Moulding sand contains previously used ground moulds (made from plaster and ground brick) held together with egg-white binder (f. 82r).]

10 The Making and Knowing Laboratory, paradoxical binders: experiments with bovine bone and rock salt, after the damp of one night (in reality, an improvised humidifier), following Ms. Fr. 640, f. 89r. Photos: Michele Goun Lee, Diana Mellon, and Yijun Wang.

crumbly mixture appears entirely implausible as a mould material, until it is left in the 'moisture of the night', or of a cellar, or other damp place, which causes long crystals to form in the salt, by which the unlikely powder is transformed into a very effective mould material that takes detail well and is extremely durable (*plate 10*).[52]

Intimacy with Materials

These paradoxical binder recipes gave us insight into the author-practitioner's bodily intimacy with materials, and the ways in which it shaped the framework of understanding that underpinned and gave meaning to his practices. The body functioned as a tool in the author-practitioner's workshop. Bodily fluids – including urine, blood, bones, saliva, phlegm, among others – were an integral part of his practice, as were foods that also sustained human growth – figs, butter, eggs, garlic, bread. Measurements were made in proportions of the human body – as much as could be held in two hands, 'two-fingers high' (161v), 'as tall as a man' (168v), a 'handspan' (16r). But the body was more than a tool in production, for the body and the materials of work interpenetrated each other, as when the metalworker inhaled the metals' cold vapours.[53] Both humans and metals had to be tempered and brought into balance by the ingesting of certain substances to counteract undesirable states, such as excess coldness or heat.

The polarities of Aristotelian qualities – hot, dry, wet, and cold – formed a fundamental structuring framework for early modern technical processes and the knowledge that emerged from them, but our study of Ms. Fr. 640 and our examination of other technical writings showed that another set of qualities also informed craft practice: we encountered a persistent paradigm of binary qualities, including hard–soft, brittle–malleable, sour–sweet/soft (*doux*), and fat–lean. The fat–lean binary is common in early modern metalworking and mining texts (and is reportedly still in use by German founders). It appears that the concept of a generative 'fat' emerged out of the practice of agriculture, in which rich, unctuous soils produced bountiful crops, as well as from foundries in which investment and mould materials were made from a buttery unctuous clay produced by long fermentation of clay and wool (as Benvenuto Cellini tells us in the *Two Treatises*). Fat earths were central in mine prospecting, 'stone marrow' being sought in mines; in the seventeenth century, an ambitious chymical practitioner, Johan Rudolf Glauber, and a Leiden professor, Herman Boerhaave, identified fatty earth with the substance out of which metals could be generated, and it remained an object of investigation into the nineteenth century. For seventeenth-century (al)chemical theorists, 'Fatty earth' (*terra pinguis*) would come to be seen as a foundational and transformative element in many material processes, even of interest to Isaac Newton, and informing the concept of 'phlogiston' and then 'oxygen'.[54]

In our experiments in the Making and Knowing laboratory, we came to understand the meaning of fatty sand in sensory terms. In reconstructing paradoxical binders,

we struggled with the concepts of fat and lean, as they did not make sense within a modern understanding of salts, much less of fat. The meaning of these terms began to dawn with the grinding and storage of rock salt for the 'Eau Magistra' of fol. 84r. When the researchers returned to the lab a few days later, they found the texture of the salt had become 'sticky'. As they recorded, 'the salt had transformed from a fine, dry powder that poured freely from an outstretched hand to a sticky substance, in which the particles clearly adhered to each other, creating an unexpected sensation of resistance when running one's fingers along the surface. The well-known material of salt unexpectedly possessed a completely different set of properties, and we *felt* the "fattiness" of the rock salt, which suddenly afforded a new workability. This allowed us to apprehend the place of "fatty" in the "science" of the author-practitioner, a rather different perspective than is given by our modern classification of salt as sodium chloride. We thus concluded that these terms, fat and lean, rely very directly upon sensory interaction with materials. Our abstracted modern understanding of this material through its chemical composition differs from the early modern practitioner's, which was a deeper, more intimate knowing through the bodily senses. This intimacy between practitioner and material was close, and sensory testing of materials and ingesting food for medicinal ends were not separated by a great distance – both involved the same types of substances and qualities, including cold, hot, wet, dry, fat, and lean, and both contributed to the intimate connection between practitioner and materials that helped reinforce an understanding of materials in the language of qualities and properties that could be apprehended by the senses.'[55]

In *The Nature and Art of Workmanship*, David Pye regards the effort to transform materials in sculpture, and the representation of that transformation, as part of an aesthetic system: 'perhaps the most constant and delightful aesthetic phenomenon throughout the history of sculpture has been this very expression in hard stone of the properties of soft materials like flesh, hair, and drapery. The stone remains recognizably stone yet the hair is recognizable as hair and the cloth as cloth.' According to Pye, this effort constitutes the essence of skill, or, as he terms it, 'workmanship', as the craftsperson strives to produce objects that display diversity, durability, and equivocality (by which he means a metal showing both its properties of liquid and solid, for example, in a sculpture).[56] To Pye's insight, we can add that the craftsperson also strives to imitate and even compete with the artifice of nature in such an effort. Such imitation and rivalry possessed a long and important genealogy in European craft and art, of course, embodied above all by the enduring employment of Ovid's *Metamorphoses* in discussing and representing natural and artistic process. But, more significantly, we should also see this fascination with transformation as a fundamental part of responding to the challenges that arise in working with the materials of nature, and the exploring, testing, trying by which a practitioner comes to understand the properties and behaviour of these materials. The polarities in metalworking recipes and the efforts to overcome and transform them, then, articulated a mode of work, as well as a framework for working and thinking through the properties of materials and the processes and products they made possible.

Mode of Work: Practice as Investigation of and Experimentation with Materials

This mode of work emerges from human interaction with natural materials – arguably an interaction that has gone on since the dawn of humanity – and can be understood as an essential component of artisanal practice. It was understood as such by sixteenth-century practitioners, who expressed the need for repeated trials of materials.[57] In Ms. Fr. 640, this mode of work is expressed in material terms, for example by the pervasive use of sulfur. In alchemy, sulfur along with mercury is one of the fundamental principles of

all metals. But in Ms. Fr. 640, research determined that 'sulfur is used quite practically, as a casting material because its capacity for accepting detail is excellent, and when its deficiencies as a material (its color, luster, or brittleness) make it inappropriate for certain tasks, the author suggests augmenting it with other materials. That sulfur is used in so many other ways, including as an ingredient in pigments and in a variety of other recipes, attests not only to the material's availability and versatility, but perhaps more significantly, its *perceived* versatility. For all of the different uses documented, one can infer that others were tried but did not produce a desired result. The prevalence of sulfur in recipes ranging from coloring to casting to using it to 'boil an egg in cold water without fire' (fol. 35r) provides evidence that the material was both commonly used and tried in a breadth of applications. Even in its uses in processes of casting explored in our reconstructions, one of its purposes appears to have been to experiment with the level of detail one can achieve with a carved pattern or mold.[58] It would seem, then, that, in its ubiquity in trying and testing in this manuscript, sulfur both connoted the idea of experimentation and, as a versatile material, invited further actual trials. Therefore it may not be too speculative to suggest that sulfur metonymically represents the process of trying and assaying, or in other words, of "experimenting" itself.'[59]

11 Wenzel Jamnitzer, *Nautilus Ewer*, c. 1570. Gilded silver, partially enamelled, height 32.5 cm. Munich: Schatzkammer der Residenz. Photo: Bayerische Verwaltung der staatlichen Schlösser, Gärten und Seen.

Conclusion

The research carried out by the Making and Knowing project demonstrates that Ms. Fr. 640, and perhaps other early modern recipe books that recount the working of materials and the production of objects, can reveal systems of belief and knowledge, as well as testify to the material, physical, and philosophical engagement of craft with the generative and transformative powers of nature. Ms. Fr. 640 demonstrates that practice (and craft knowledge more generally) was not just productive, but also investigative and 'philosophical'. The author-practitioner's investigation extended seamlessly from exploration of the properties of oyster shells, egg white, metals, sulfur, resin, oils, and all manner of other materials to natural historical observation and experiment. We can see this intersection of craft practice – the moulding, casting, experimenting – with natural historical observation in Ms. Fr. 640 in one further example: the author-practitioner relates where certain animals can be found, their hibernation and feeding habits – even experimenting on snakes to see if they vomit up the live frogs they swallowed – and notes methods for keeping them alive in captivity, and then finally for killing and casting them.[60] This de facto natural historical investigation appears to be represented in the final life-cast objects themselves. Of course, no objects created by the author-practitioner of Ms. Fr. 640 are known to be extant, but he does include instructions for catching, feeding, killing, and casting snakes, as can be found in many extant nature casts, such as Wenzel Jamnitzer's *Nautilus Vessel*

12 Detail of Jamnitzer, *Nautilus Ewer*, showing grass snakes, cast from life. Photo: Pamela H. Smith.

in the Munich Residence Museum (*plate 11*). This fantastical object portrays a mass of common grass snakes at its base, all much the same length and age. I would argue that this object replicates the experience of snake catchers and collectors as they searched out specimens for casting. A film that records the experience of finding a brood nest of snakes conveys this experience vividly (*plate 12*).[61] This codification in metal of practical observation and experience shows clearly the ways in which craft making, such as that articulated in the folios of Ms. Fr. 640, informed and intersected with the emergent modes of scientific thinking and knowing in the sixteenth century.

Over the following centuries, during the period of what is known as 'the Scientific Revolution', the collaboration and experimentation of the craft workshop would go on to be integrated into the practice of the natural sciences. In the course of this integration, the shared origins of art, history, and natural science were obscured. But much can be gained by renewing a dialogue among the arts, history, and natural sciences, and by resuscitating the concept that the investigation of nature and of the human world are deeply entwined, as sixteenth-century natural historians took for granted, and as modern sociologists of science, environmental historians, and climate scientists have recently begun to emphasize.

Appendix

The Making and Knowing Project[62] began in June 2014 with the first of three annual middle French paleography workshops. Working in a collaborative digital space of Google Drive, these workshops teach paleographic skills to about fifteen students already proficient in modern French who then gain practice as they transcribe and translate the manuscript. As they work, they make use of all kinds of reference sources, and their collectively compiled list of dictionaries, texts, and encyclopaedias

of early modern techniques and materials is one of the unexpected byproducts of the project. Paleographers annotate the text with comments about sources used and translation choices.

The paleographers' translation forms the basis for a laboratory seminar held each semester, in which students reconstruct some of the recipes in the manuscript – in 2014–15, the courses focused on mouldmaking and metalworking recipes in Ms. Fr. 640;[63] in 2015–16 on colour-making recipes. To reconstruct the recipes, the students must engage in conventional text-, document-, and object-based historical research in order to begin to understand terminology and process, gain a sense of the object that is the goal of the recipe, and try to construct a 'genealogy' for the recipe in order to make clear whether the author-practitioner was drawing upon published (or manuscript) texts. As they work, students take field and laboratory notes, stored on a collective Wiki, in which they record their reconstruction experiments as well as their experience as history students doing hands-on work in a laboratory. In these field notes, as in the entire project, we strive to reflect on the methodology and epistemology of reconstruction – how can we responsibly make use of reconstruction as historical evidence? By the end of each semester, students synthesize their research into annotations on individual recipes in the manuscript which will serve as the final critical commentary of the edition.

The laboratory seminars begin with skill-building exercises, including reconstructing historical culinary recipes (generally not from the manuscript, as it contains very few food recipes), which the class then discusses and (literally) digests. This exercise aims to spur the students into considering the methodological challenges of reconstruction, as well as to formulate a template for a rigorous reconstruction procedure. From culinary recipes, the students moved in 2014–15 to related entries in Ms. Fr. 640, such as bread-moulding. These exercises provided insight into the mechanics of direct and indirect casting as did the subsequent exercises of moulding and casting in cuttlefish bone and producing 'sands' and 'binders' to carry out box moulding. For two weeks in 2014, an 'expert practitioner', Tonny Beentjes, Programme Leader in Metalwork, University of Amsterdam, led the students in sand casting in box moulds, and Andrew Lacey, Sculptor and Independent Scholar, led life-casting in plaster in spring 2015.

For the remaining eight weeks of the semester, students work in groups of two or three on reconstructions of up to three recipes in the manuscript. Aiming for much more than simple accounts of hands-on reconstructions, the students write up their research as an answer to a historical question that their hands-on reconstructions helped to answer. In all cases, the students' annotations must form an integrated text that weaves together in a single narrative both conventional historical research based on documents, texts, and objects with more 'subjective' hands-on historical experiments to make an argument about what research into the recipe reveals. An extensive editing process follows, including two collective revision workshops, and often quite far-reaching revisions by the Making and Knowing Team. At the end of the second semester, a Working Group Meeting is convened, including all students from the two courses, the Making and Knowing team, the two Expert Makers, and a group of scholars, expert in the year's theme, who have had access to the contents of the Wiki and Google Drive throughout the year. This final capstone to the year's research brings both additional expertise into the project, and provides for critical oversight on the student work.[64]

The annotations that formed much of the basis of this article were authored by the Making and Knowing Team (Director Pamela H. Smith; Making and Knowing Postdoctoral Scholars Donna Bilak, Jenny Boulboullé, Joel Klein; Paleography Co-Director Marc H. Smith); students from the 2014–15 Columbia laboratory seminar,

Hist G8906: Craft and Science: Making Objects in the Early Modern World (Emily Boyd, Raymond Carlson, Emogene Cataldo, Giulia Chiostrini, Celia Durkin, Shiye Fu, Sofia Gans, Jordan Katz, Rozemarijn Landsman, Michelle Lee, Caroline Marris, Diana Mellon, Jef Palframan, Stephanie Pope, Jonah Rowen, Julianna Van Visco, Yijun Wang, Zhiqi Zhang); students in the University of Amsterdam MA in conservation and restoration of cultural heritage, metals specialization course (Michaela Groeneveld, Ingeborg Kroon, Elisabeth Kuiper and Marianne Nuij); and a student from the V&A/RCA PhD in History of Design (Maria Alessandra Chessa).

The Making and Knowing Project is collaborating with several institutions, including the Technical Art History Group at the University of Glasgow (Erma Hermens and Mark Richter); Conservation Programmes at the University of Amsterdam (Marjolijn Bol, Tonny Beentjes, Tamar Davidowitz, Ellen van Bork, and Maartje Stols-Witlox); the Victoria & Albert Museum-Royal College of Art Postgraduate Programme in the History of Design (Marta Ajmar); Bard Graduate Center for Decorative Arts, Design History, and Material Culture (Deborah Krohn); the Independent Research Group on Art and Knowledge in Premodern Europe at the Max Planck Institute for the History of Science (MPIWG) (Sven Dupré); the Recipes Project (Elaine Leong) at the MPIWG, and the Colour ConTEXT database compiled by the MPIWG in conjunction with the University of Liège.

A note on authorship and terminology: 'I' refers to Pamela Smith, the principal author of this article, whereas 'we' refers, according to context, to Pamela Smith and Tonny Beentjes, or the Making and Knowing Team and students from Hist G8906 in the 2014–15 academic year.

Notes

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1 For the development of natural history, see Gianna Pomata and Nancy Siraisi, eds, *Historia: Empiricism and Erudition in Early Modern Europe*, Cambridge, MA, 2005; Brian W. Ogilvie, *The Science of Describing: Natural History in Renaissance Europe*, Chicago, IL, 2006.

2 Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution*, Chicago, IL, 2004.

3 Benvenuto Cellini, *Trattati dell' Oreficeria e della scultura* (completed by 1565, published 1568), here *Two Treatises on Goldsmithing and Sculpture*, trans. C. R. Ashbee, New York, 1967, 19.

4 Bernard Palissy, *Admirable Discourses on the nature of waters and fountains, either natural or artificial, on metals, salts and salines, on rocks, earths, fire and enamels…. The whole arranged as dialogues, in which are included theory and practice* (1580), trans. Aurele la Rocque, Urbana, IL, 1957.

5 Theophrastus von Hohenheim called Paracelsus, *On the Miners' Sickness and Other Miners' Diseases*, trans. George Rosen, *Four Treatises of Theophrastus von Hohenheim called Paracelsus*, ed. Henry E. Sigerist, Baltimore MD, 1941, 91.

6 For these developments, see Pamela H. Smith, 'Making things: Techniques and books in early modern Europe', in Paula Findlen, ed., *Things*, London, 2013, 173–203, and Pamela H. Smith, 'Craft techniques and how-to books', in Mark Clarke, Bert De Munck and Sven Dupré, eds, *Transmission of Artists' Knowledge*, Koninklijke Vlaamse Academie van Belgie voor Wetenschappen en Kunsten, 2012, 75–84.

7 See http://www.jove.com/.

8 I examine these questions in Pamela H. Smith, *From Lived Experience to the Written Word: Recovering Art and Skill in Early Modern Europe*, in preparation.

9 See for example, William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture*, Princeton, NJ, 1994; see the scholarly essays in vol. 3 of Michael of Rhodes, *The Book of Michael of Rhodes: A Fifteenth-Century Maritime Manuscript*, 3 vols, ed. Pamela O. Long, David McGee and Alan M. Stahl, transcription by Franco Rossi, trans. Alan M. Stahl, Cambridge, MA, 2009; and Eleanor Robson, 'Technology in society: Three textual case studies from late bronze age Mesopotamia', in Andrew J. Shortland, ed., *The Social Context of Technological Change: Egypt and the Near East, 1650–1550 BC*, Oxford, 2002, 39–57.

10 Available on Gallica, http://gallica.bnf.fr/ark:/12148/btv1b10500001g/f1.image), with the library title 'Recueil de recettes et secrets concernant l'art du mouleur, de l'artificier et du peintre'.

11 The binding, stamped and gilded with the arms and device of Philippe de Béthune (1565–1649) indicates that the manuscript was part of the bequest of the Béthunes to the royal library in 1662 (registered by Parlement in 1664). Orthography and various dates within the manuscript reveal that it was composed after 1581 and probably before 1600. Watermarks on the endpapers differ from the text block, indicating that the pages were rebound (as does the double set of page numbers). The watermark on the text block is that of the papermaker Nicolas Lebé of Troyes, active c. 1561–96.

12 Study of the *Kunstkammer* began with Julius von Schlosser, *Die Kunst- und Wunderkammern der Spätrenaissance*, 1908; reprint edition: 2 vols, Braunschweig, 1978, and has increased dramatically since the 1980s, especially with publication of Oliver Impey and Arthur Macgregor, eds, *The Origins of Museums: The Cabinet of Curiosities in Sixteenth- and Seventeenth-Century Europe*, Oxford, 1985, and the founding of the *Journal of the History of Collections* in 1989. For a useful introduction, see Thomas DaCosta Kaufmann, 'From mastery of the world to mastery of nature: The *Kunstkammer*, politics, and science', in Thomas DaCosta Kaufmann, *The Mastery of Nature: Aspects of Art, Science, and Humanism in the Renaissance*,

Princeton, NJ, 1993; Martin Kemp, '"Wrought by no artist's hand": The natural, the artificial, the exotic, and the scientific in some artifacts from the Renaissance', in Claire Farago, ed., *Reframing the Renaissance: Visual Culture in Europe and Latin America 1450–1650*, New Haven, CT and London, 1995, 117–96; and Horst Bredekamp, *The Lure of Antiquity and the Cult of the Machine*, trans. Allison Brown, Princeton, NJ, 1995.

13 Most recently on books of secrets, see Elaine Leong and Alisha Rankin, eds, *Secrets and Knowledge in Medicine and Science, 1500–1800*, Aldershot, 2011.

14 Female authorship of BnF Ms. Fr. 640 is not impossible, but appears highly unlikely in light of the orthography, as well as the accounts of travel and the knowledge of other workshops contained in it.

15 Anon., *Der 'Liber illuministarum' aus Kloster Tegernsee*, ed. Anna Bartl, Christoph Krekel, Manfred Lautenschalger and Doris Oltrogge, Stuttgart, 2005; and Anon., *Mediaeval Painters' Materials and Techniques: The Montpellier Liber Diversarum Arcium*, ed. Mark Clarke, London, 2011.

16 Vannoccio Biringuccio, *The Pirotechnia*, first published 1540, trans. C. Stanley Smith and M. Teach Gnudi, New York, 1943.

17 For more on life-casting and BnF Ms. Fr. 640, see Pamela H. Smith and Tonny Beentjes, 'Nature and art, making and knowing: Reconstructing sixteenth-century life-casting techniques', *Renaissance Quarterly*, 63, 2010, 128–79, and for more on our life-casting reconstructions, see Pamela H. Smith, 'In the workshop of history: Making, writing, and meaning', *West 86th: A Journal of Decorative Arts, Design History, and Material Culture*, 19, 2012, 4–31. See most recently, Giulia Chiostrini and Jef Palframan, 'On moulding a rose', http://bit.ly/1hWo6ZI.

18 For a fuller treatment of this, see Pamela H. Smith, 'Between nature and art: Casting from life in sixteenth-century Europe', in Elizabeth Hallam and Tim Ingold, eds, *Making and Growing: Anthropological Studies of Organisms and Artefacts*, Aldershot, 2014, 45–63.

19 Among the many YouTube videos of catching lizards by suspending a slip knot from a stick (as the manuscript advises), see https://www.youtube.com/watch?v=j0pMlAXwuVs.

20 See Smith, 'In the workshop of history'.

21 Smith, 'In the workshop of history'.

22 Francisco Alonso-Almeida, 'Genre conventions in English recipes, 1600–1800', in Michelle DiMeo and Sara Pennell,eds, *Reading and Writing Recipe Books, 1550–1800*, Manchester, 2013, 68–90, calls recipes a 'hive discourse' to indicate this dimension.

23 http://www.makingandknowing.org/.

24 Syllabus for the Spring 2015 course: http://bit.ly/1JOwFSK.

25 For examples of the kinds of evidence reconstruction makes possible, see chapters 1–2 in *Art of the Past: Sources and Reconstructions: Proceedings of the First Symposium of ATSR Study Group*, London, 2005; Maartje Stols-Witlox, 'Sizing layers for oil painting in Western European sources (1500–1900): Historical recipes and reconstructions', in S. Kroustallis and Joyce H. Townsend, *Art Technological Research: Towards a New Discipline. Proceedings of the Second ATSR Symposium*, London, 2008, 147–65; Ken Albala, 'Cooking as research methodology: Experiments in Renaissance cuisine', in Joan Fitzpatrick, ed., *Renaissance Food from Rabelais to Shakespeare: Culinary Readings and Culinary Histories*, Aldershot, 2010, 73–88; and Adelheid Voskuhl, 'Recreating Herschel's Actinometry: An essay in the historiography of experimental practice', *British Journal for the History of Science*, 30: 3, 1997, 337–55.

26 Hasok Chang, 'How historical experiments can improve scientific knowledge and science education: The cases of boiling water and electrochemistry', *Science and Education*, 20, 2011, 317–41. One of the challenges faced by the Making and Knowing Project is the lack of expertise among the individual student researchers on the project. The laboratory seminars do no more than give individual students brief exposure to the experiential knowledge of materials and techniques – really just make them aware of what they do *not* know. It is thus surprising how much the collective nature of the project and the many collaborators with different levels of expertise make up for this lack of expert individual engagement.

27 Deciphering marginalia: Emogene Cataldo and Julianna van Visco, on 'Deciphering Marginalia: Try burnt oysters', http://bit.ly/1PuYjCF; clues to author-practitioner's identity: Rozemarijn Landsman and Jonah Rowen, 'Original Patterns in Ms. Fr. 640', http://bit.ly/1h9c1zO; and Raymond Carlson and Jordan Katz, 'Roses', http://bit.ly/1ER4j2K; techniques outside France: Sofia Gans, 'Knowledge Transmission in Ms. Fr. 640', http://bit.ly/1Ee9tem; learning new techniques: Shiye Fu and Zhiqi Zang, 'Too thin Things', http://bit.ly/1JrUvgH; and Chiostrini and Palframan, 'On Molding a Rose'; failures: Raymond Carlson and Jordan Katz, 'Casting in a Box Mould, fol. 118v', http://bit.ly/1PuYQV6.

28 Rozemarijn Landsman and Jonah Rowen, 'Fol. 92v: Molding a Hollow on One Side and a Relief on the Other (incuse reverse cast medals)' http://bit.ly/1MIJUDu; and Michaela Groeneveld and Marianne Nuij, 'Concerning the Incuse Reverse Casting of Medals', http://bit.ly/1PMVu0y.

29 Elisabeth Kuiper and Ingeborg Kroon, 'What is Spat?', http://bit.ly/1hWKSRf.

30 Experiential knowledge: Caroline Marris and Stephanie Pope, 'Sand with ox foot bone and elm root', http://bit.ly/1NwyAfw; Impalpable: Cataldo and Van Visco, 'Deciphering'; Carlson and Katz, 'Casting in a Box Mould, fol. 118v'; Sofia Gans, 'Calcined Alabaster as Excellent Sand, fol. 83v', http://bit.ly/1V50e4p; and Jenny Boulboullé and Joel Klein, 'Impalpable sand from Toulouse', http://bit.ly/1JfsutE; *s'attaque*: Celia Durkin, 'Molding fruits and animals in sugar', fol. 126r, http://bit.ly/1fBue85.

31 Mustard: Diana Mellon, 'Excellent Mustard, fol. 84r', http://bit.ly/1KHSP3O; millet consumption: Giulia Chiostrini and Jef Palframan, 'Making Millas, fol. 20r', http://bit.ly/1U2zqoy; and sand for hourglasses: Caroline Marris and Stephanie Pope, 'Powder for hourglasses, fol. 10r', http://bit.ly/1ER6Nyj.

32 As in the fluid-text edition of Herman Melville's Typee manuscript: http://rotunda.upress.virginia.edu/melville/default.xqy.

33 As, for example, in the innovative digital essay 'Kafka's wound' by the writer Will Self: http://thespace.lrb.co.uk/.

34 Fol. 150r.

35 For a full treatment of this, see Pamela H., Smith, 'Making as knowing: Craft as natural philosophy', in Smith, Amy R. W. Meyers and Harold J. Cook, eds, *Ways of Making and Knowing: The Material Culture of Empirical Knowledge*, Ann Arbor, MI, 2014, 17–47; and Pamela H. Smith, 'Vermilion, mercury, blood, and lizards: Matter and meaning in metalworking', in Ursula Klein and Emma Spary, eds, *Materials and Expertise in Early Modern Europe: Between Market and Laboratory*, Chicago, IL, 2010, 29–49.

36 Maria Alessandra Chessa, 'Imitation Coral', fol. 3r, http://bit.ly/1U2zuVe. See also the video of reconstructing the 'Imitation Coral' recipe on fol. 3r in the Making and Knowing laboratory: https://vimeo.com/129811219.

37 John Gage, 'Colour words in the high Middle Ages', in Erma Hermens, ed., *Looking through Paintings: The Study of Painting Techniques and Materials in Support of Art Historical Research* (Leids Kunsthistorisch Jaarboek XI), Baarn, The Netherlands, 1998, 35–48, 39.

38 See Pamela H. Smith, 'Itineraries of materials and knowledge in the early modern world', in Anne Gerritsen and Giorgio Riello, eds, *The Global Lives of Things*, London, 2015, chapter 1. For photographs of British Library, MS Egerton 1821, fols. 1v-2r, see https://www.bl.uk/catalogues/illuminatedmanuscripts/record.asp?MSID=8389&CollID=28&NStart=1821.

39 See for example, the information in vol. 3 of Michael of Rhodes, *The Book of Michael of Rhodes: A Fifteenth-Century Maritime Manuscript*. Further study about the use of ratios and proportions and its effects for conceptions of number in the early modern period is merited.

40 Mellon, 'Excellent Mustard'.

41 The process of 'extension' in experimentation to which Hasok Chang alludes. For evidence in the manuscript, see Cataldo and Van Visco, 'Deciphering'; Shiye Fu and Zhiqi Zang, 'Too thin Things'; Sofia Gans, 'Calcined Alabaster'; Kuiper and Kroon, 'What is Spat?'

42 Fol. 90r alludes to this searching out materials in nature.

43 'Les fondeurs prenent de la racine de jeune orme quand il est en sabe, & le font bouillir en vin ou pour mieulx vinaigre, et en font provision pour tout l'an dans un barriquet'. BnF Ms. Fr. 640, fol. 87v.

44 Deanna F. Curtis, Curator of Woody Plants at the New York Botanical Garden, suggested via email that an elm hybrid cultivar known as 'Pioneer' (binomial *Ulmus x hollandica*) might be more suitable for our purposes: as the Pioneer hybrid is formed by the crossing of two European species, *Ulmus glabra* (or Wych Elm) and *Ulmus minor* (the Smooth-leaved Elm), it probably more closely approximated the elms from which our author-practitioner would have sourced his roots. See

Caroline Marris and Stephanie Pope, 'Sand with ox foot bone and elm root'.

45 Email communication, dated 10 May 2015, from Joel T. Fry, Curator, Bartram's Garden, John Bartram Association, Philadelphia. As Dr Fry made clear, the commercial uses of plants are still considered in hybridization; but they are generally not part of the taxonomic system.

46 'Having thus moistened the sand in order to give it a nice hold, though it still came apart easily…' ['Ayant ainsy humecte le sable facon quil faisoict bonne prise sesmiant…'], fol. 118v. See Emogene Cataldo and Julianna van Visco, 'Eau Magistra': Investigating Binders for Sandcasting', and Cataldo and van Visco, 'Deciphering Marginalia: Try Burnt Oysters, fol. 84v', http://bit.ly/1NPGNIJ.

47 Cataldo and van Visco, 'Eau Magistra'; 'Deciphering'; and Marris and Pope, 'Sand with ox foot bone and elm root'.

48 Alessio Piemontese, *De Secreti*, also describes the perfect sand for casting as 'very soft, as if impalpable'. Alessio Piemontese, *Secreti del Reverendo Donno Alessio Piemontese*, Venice, 1555, 206. See also, Carlson and Katz, 'Casting in a Box Mould, fol. 118v'.

49 See Christoph Krekel and Manfred Lautenschlager, 'Bearbeitung von Glas, Edelstein, Bein und Horn', in Anna Bartl, Christoph Krekel, Manfred Lautenschalger and Doris Oltrogge, *Der 'Liber illuministarum' aus Kloster Tegernsee*, Stuttgart, 2005, 673–78. An excellent example of these kinds of recipes that attempt to bring about opposite states can be found in *Künstbüchlin gerechten gründlichen gebrauches aller kunstbaren Werckleüt*, Augsburg, 1535.

50 Emogene Cataldo and Julianna van Visco, 'Wax and Tallow: A Material Investigation', http://bit.ly/1NPGMo7.

51 Rozemarijn Landsman and Jonah Rowen, 'Concerning the uses of sulfur for casting', fols. 140v and 12r, http://bit.ly/1WOsb2a.

52 Yijun Wang, 'Powder of ox bone and rock salt, fol. 89r', http://bit.ly/1I8RYai; and Gans, 'Calcined Alabaster'.

53 Ms. Fr. 640 contains a prophylactic against metal fumes: 'In the morning, take a piece of thin toast with butter, neither antimony nor any other vapors will harm you. Or put half a pig's bladder in front of your face' (fol. 79v). For more on this, see Pamela H. Smith, 'Making as knowing: Craft as natural philosophy'.

54 For more on this, and all pertinent citations, see Pamela H. Smith, 'The matter of ideas in the working of metals in early modern Europe', in Christy Anderson, Anne Dunlop and Pamela H. Smith, eds, *The Matter of Art: Materials, Practices, Cultural Logics, c. 1250–1750*, Manchester, 2015, 42–67.

55 Michele Goun Lee, with Pamela H. Smith, 'Eau Magistra, fol. 84v', http://bit.ly/1U2zWCK.

56 David Pye, *The Nature and Art of Workmanship*, Cambridge, 1968, 47.

57 For example, Biringuccio, *Pirotechnia*, 114.

58 Cellini recommends that 'you will do well to make wax impressions from time to time, while you are cutting, to see how you are getting on'. *The Two Treatises*, 73–4.

59 Landsman and Rowen, 'Concerning the uses of sulfur'.

60 Another example of the intersection between natural historical and craft interests can be found in the author-practitioner's terms for the techniques of life-casts – he calls the channels by which metal enters the mould 'veins', and the tubes by which ashes can be blown out of the mould after burnout and by which air escapes as metal replaces it in the pour 'breathing holes'. See Chiostrini and Palframan, 'On Molding a Rose'.

61 https://www.youtube.com/watch?v=W6sxEf997iM. See the sequence at 57 seconds into the video. I thank Joosje van Beenekom, Senior Metals Conservator, Rijksmuseum, Amsterdam, for informing me of this film.

62 For further information on the Making and Knowing Project, see http://www.makingandknowing.org/. For photographs of much of the work done in the Project, see its Flickr site https://www.flickr.com/photos/128418753@N06/albums.

63 Syllabus for the Spring 2015 course: http://bit.ly/1JOwFS.

64 The first Working Group Meeting on Moldmaking and Metalworking in BnF Ms. Fr. 640 was held 27–30 May 2015. Meeting Programme at http://bit.ly/1U2Ab0Q.