Reading instruments for historical scientific practice

An experiential pedagogy for material culture

Alistair Kwan

1 Plato’s Curse

(14) Teaching with or about historical scientific instruments can be hard.1 Students commonly respond by classifying the object or its purpose: “It’s a spectroscope.” “It’s for measuring how much a dog salivates.” “It proved that most of the atom is concentrated in a tiny nucleus.” The classification instinct is strong, and only natural, for classification and correctness often dominate how science is taught. Even as curricula prescribe a focus on process and the nature of science, assessment commonly emphasises the faithful rehearsal of well-defined knowledge received from all-knowing experts. Expert knowledge includes knowledge of scientific instruments, for scientific instruments are designed for experts to use, so only experts are expected to understand them. To the rest of us, the instrument may be mysterious, even unintelligible: a steampunk contraption of brass and glass, or a sci-fi panel of buttons and dials and flashing lights. Once the object’s mysterious identity has been profaned by revelatory classification, many students think that the job is done.

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1. The first sketch of this essay was presented at the XXXIV Scientific Instrument Symposium (Turin, 7–11 September 2015), part of which was printed as Alistair Kwan, "Interpreting Tools by Imagining Their Uses", Journal of Museum Education 42 (2016), pp. 69–80. The ideas were further developed through presentations and conversations at CAUMAC (Canberra, 2018), ICOM–ICR/ICTOP (Auckland, 2018), and the Knowledgeable Object Symposium (Macquarie University, 2018), and of course through the generosity of this volume’s and series’ editors.
By naming the object, students demonstrate competence in the way typically modelled by experts in lectures and on television: they give the thing a name, perform expertise through jargon, and perhaps assert an important application for the knowledge that the device is used to produce (most likely in the passive voice). Following cues in curriculum and popular media alike, our students privilege formal, codable knowledge that can be put into words, explained in lectures, and written up in journal articles, books and archives. The historical object, in such settings, is not an evidentiary source about scientific or technological history, but only a material echo of The Sacred Word, a mere handservant of The Knowledge That Matters.

An actual expert’s knowledge of the instrument, of course, goes far beyond what books and archives contain. Moreover, there are many different experts whose knowledge only partially overlaps. The expert operator, for example, knows how to use the instrument: how differently it behaves on humid days, how to turn the knobs without losing accuracy to a loose screw, which windows or dials to watch when, what the occasional wobble on the left signals, and how to prevent that wobble from happening. Expert operators might speak of the instrument in the passive, but they operate their instruments in dialogue, responding to the instrument, even collaborating with it. The expert maker, in contrast, knows that certain odd holes and notches are for registration during milling or assembly (or were actually mistakes that can be excused by calling them registration holes), that certain parts must be fitted before others, that certain adjustments are going to entail re-applying half of the lacquer. The expert laboratory technician knows how which consumables work best (perhaps contrary to the maker’s advice), and which eyepiece or valve was actually borrowed from another instrument. Expert knowledge – from the plurality of experts that instruments may involve – is rich, multiple, thick.

But what if you aren’t an expert? Chances are that none of our students are experts. For instruments from a century past, we teachers will not be experts either, at least not the experts who designed or made the instrument, or who used or maintained it in everyday work. While original context is certainly among the goals of material culture analysis, the largely practical knowledge of instruments – and tools more broadly – can be difficult to extract, and may be missed altogether as attention inclines towards names, theories and categories. This essay searches for a theoretical perspective by which to complement that formal, codable knowledge with the kinds of historical expert knowledge that the object’s makers, operators, technicians used to possess. Even though that knowledge is largely practical, our journey here will be more theoretical: the goal is a bridge, or at least its footings, that will contribute in a historiographically significant way to the teaching and learning of history of science. Our starting point is something that many instruments share in common: that they were designed to serve a purpose, and that they were designed for people to use them. Because design is deliberate, it offers a way to understand an object in front of us.  

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2. See also Paolo Brenni’s chapter in this volume; infra, pp. 34–49.
2 Design Theory and the Psychology of Our Surroundings

Many scientific instruments were designed for operation by ‘typical’ human operators, expressing thoughts through ‘typical’ human bodies. Good tools ‘fit’ our bodies. We are good at identifying actions that tools invite us to perform: we instantly spot buttons to push, handles to grasp, levers to pull, holes to peer into. Spotting them is so natural that, when an object does not respond as expected, we may reflexively blame the object or designer without even noticing whence our expectations originated – we perceive the handles, levers, viewports, buttons, knobs or switches without any effort at all, but how do we know what they are?

The process of perceiving these action-components is both tricky to spot and tricky to work with, hence our struggle to foresee and correct shortcomings that undermine disabled people, for instance, by lacking good ways to think about them. Or we answer confusion with an exhortation to read the manual more carefully, not aware that something is systematically guiding operators in a different direction. Several key ideas, however, have been brought together as Design Theory, enabling them to be used both for design, and also for the analysis of spaces and objects – whether designed or not.

Design theory originates in ecological psychology, an approach that treats action and perception as inseparable. In James Gibson’s formulation, which has recently gained prominence in education theory, the environment presents potential for action. Objects’ shapes, their locations, and their dimensions communicate possibilities like ‘pushable’, ‘graspable’, ‘step-on-able’. In other words, we perceive not merely forms, but also what we can do to them. A button typically communicates pushability by standing slightly proud of the surrounding surface, being about the size of a fingertip, often with a slight depression to welcome and direct the finger’s touch, and often a thin gap between it and the sleeve or faceplate that it slides into. A handle declares its graspability by being thin enough to wrap the hand, or at least fingers, around. It may be raised clear of the surface behind it so that fingers can fit into the gap; it may swell in the middle to nestle into the palm, or have a sequence of grooves to accommodate the fingers, or knurling that declares a better grip. A ‘step-on-able’ surface is horizontal and large enough to fit a foot or two; if somewhere between floor and knee level, it presents as an opportunity for climbing up or down, especially if there are several of them in a regular sequence, that is, stairs. A larger

3. Exceptions might include automated instruments, or instruments operated by computers. Space telescopes, remote-sensing satellites, self-registering data loggers and wireless-activated or animal-triggered observation stations, for example, would resist the methods outlined here. So would instruments accessed through an intermediary, such as isolated sensors engaged via a cable or a computer.

horizontal surface at knee level can read also as ‘sit-on-able’. These mechanical potentials, in James Gibson’s parlance, are called “affordances”.5 Affordances underpin the skeuomorphic design of computer screen interfaces that look like physical reality: on-screen buttons and slide-switches mimic their mechanical counterparts in order to communicate, without words, how to operate them. To put it another way, we perceive the world through functionality, what an Aristotelian might call τέλος or ‘final cause’. A garden path, for example, is not only the matter of its paving stones nor the long, thin form in which they are arranged, but also the line of footholds that the stones, arranged in this way, affords. Its final cause is to be walked along.

On top of affordances, there can be cultural and logical information. Two buttons arranged side-by-side are likely to have opposing outcomes: on and off, or left and right if aligned horizontally, or up and down (or forwards and backwards) if aligned vertically. A row of identical buttons is likely to activate gradations of a single action, such as for selecting the destination storey in an elevator. Colour-coding, symbols or a numerical sequence may offer further guidance – in an elevator, a star often indicates the main street connection regardless of how the storeys are numbered. Extending Gibson’s purely physical affordances to embrace meanings cued through cultural norms or abstract reasoning leads to a more complex phenomenon that goes by various names; here, we will use Krippendorf’s term, “affording”.6

Getting the affordances and affordings right may well be design’s most important goal. When design is ‘good’, no one needs instruction: the affordances and affordings do their job so well that the user effortlessly intuits what (18) to do, and the affordances and affordings go unnoticed. If they go unnoticed, however, how can affordances and affordings be seen?

Consider the object in Figure 1. This object often defies efforts to classify it. The object taunts us by making every feature mockingly apparent, unobscured by ornamentation or enclosures. Touching the shiny surface, we find that it is hard and smooth. Its shape evokes space rockets and car hood ornaments as imagined in the 1960s, or extraterrestrial robots imagined in a 1990s blend of minimalism and teuthoid biomimicry. But what is it? It does not seem to say; perhaps the best we can call it is ‘sculpture’.

(19) To many people, this object makes no sense until the grooved central bulb is identified as a citrus reamer. With that insight in hand, the mind swings immediately onto a different track: we imagine holding a halved lemon or orange on top, pressing down and turning, while the other hand holds one or two of the legs. We imagine the juice running down the grooves and coming together to stream off the central point below, and surmise

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5. Gibson’s definition of affordance is diffuse and discursive, and was spread over many years. While not the first clear instance of the concept, a source that has come to be canonically cited is James Gibson, The Ecological Approach to Visual Perception, Erlbaum, Hillsdale (NJ), 1986, pp. 127–145. The understanding of ‘affordance’ taken in this essay is strictly ecological and perceptual, following Gibson. It does not include functionalities that do not communicate themselves within the operator’s immediate perceptions, and hence differs from the broader ‘what it can do – even if the operator can’t tell’ sense of affordance (more accurately called functions or potential) widely meant in the e-learning literature.

6. For an explanation of “affording” more pointed than Gibson’s, see Krippendorf, op. cit. (n. 4), p. 120.
Figure 1: Philippe Starck, *Juicy Salif*, 1990, for Alessi
Photo by Jonas Forth, 2013, www.flickr.com/photos/jforth/8524644379, CC BY-ND 2.0
that the space underneath is just the right size to slip a glass or small jug underneath. That is, in fact, what a buyer learns from the instruction sheet in the box.

Notice how the meaning-making shifted from considering, at a distance, an abstract, deliberate form to a concrete, intuitive imagining of bodily action, and then from bodily action to abstractly deducing the potential to slip a drinking glass underneath. Juicy Salif, a 1990 design by Philippe Starck, plays on a Plato–Aristotle complementarity between the formal and material modes of interpreting the world. The form–matter insight, not lemon juice, is what Juicy Salif really extracts.

Affordances can be communicated more jarringly through poor design. Every university, for instance, seems to have a door with ‘pullable’ handles mounted on the ‘push’ side. We often discover these handles by responding to the design feature exactly as it tells us we should, regardless of the signs that command us to “push”. Some of us learn about this ‘special character feature’ of institutional ‘architecture’ under the squeal of a fire alarm, when pulling on the handle interrupts urgent egress: that confrontation shows how the material environment directs us far more clearly than the administrators’ signage, and that it really does matter.

Such visceral engagement is exploited by Katerina Kamprani, a contemporary architect who developed a set of objects to help us “appreciate the complexity and depth of interactions with the simplest of objects around us”.

Each of these objects is a variation of something so commonplace that its affordances and functionalities, taken for granted, go unnoticed. Each of these objects has been rendered useless by one carefully chosen change, and the uselessness is so obvious that it draws attention to an affordance or another functional property that few of us ever really thought about. Several of the objects (Fig. 2) depend on handle position: a wide stockpot has both of its handles on the same side so it cannot be held level without inordinately strong forearms; a briki (a jug for brewing Turkish and Greek coffee) has its handle relocated directly under its spout, so hot coffee would pour onto the user’s hand. These objects communicate because we naturally imagine holding the handles. Kamprani’s chairs include one with a hard bulge in the middle of the seat, prompting us to imagine how it feels to sit there, and another with over-extended arms that require us to climb over them, or to be lowered in like an infant into a high chair. Kamprani’s objects prompt sensory imaginations that combine proprioception and pain and annoyance and difficulty and tiredness: we imagine bodily discomfort.

7. Starck is widely claimed to have said that Juicy Salif is “not meant to squeeze lemons; it is meant to start conversations”. For further analysis of how Juicy Salif is interpreted, see B. Russo and A. DeMoraes, “The Lack of Usability in Design Icons: An affective case study about Juicy Salif”, DPPi03: Proceedings of the 2003 International Conference on Designing Pleasurable Products and Interfaces, Pittsburg (PA), ACM Press 2003, pp. 146–147; P. Lloyd and D. Snelders, “What was Philippe Starck Thinking of?”, Design Studies 24 (2003), pp. 237–253.

Figure 2: Some of Kamprani's uncomfortable objects Photos by Simon Berry, Bad Design, www.flickr.com/photos/colalife/albums/72157645617459712, CC BY-SA 2.0
How might these ideas be applied in the classroom? More to the point, to what new understandings of historical scientific instrumentation could those applications lead?

3 Didactic Experiences

Many art educators begin class with a simple question: “What do you notice?” That question immediately shifts the emphasis off ‘scholarly’ categories (period, style, medium, genre, artist) to personal perceptions. Asked what they notice, learners take numerous directions, responding, for example, to material, shape, similarities, evocations, textures, proportions, size, heft. They might notice motifs that support a stylistic reading, or geometries for a structural reading. They might notice knobs or handles or other affordance-related features, leading towards a reading in terms of handling.

Sextants and octants, for example, offer a puzzling mixture of see-through circles and what appears to be an eyepiece (Figs. 3, 4, 5). There is a hinged arm whose free end slides across an angle scale. And there is sometimes – but not always – something on the back, or underside, that might look like a handle. Many people find that the arrangement makes no sense. The first few times I saw a sextant, they made little sense to me either, regardless of the many diagrams and historical mentions I had previously read. The handle was especially confounding: explanatory diagrams often did not show a handle, and many sextant handles do not look like the handles that most of us are familiar with. On some instruments, the handle looks more like a mounting bracket or a counterweight, or a decorative element yet to be carved with a coat of arms, or even just a projection to hold the sextant secure in its case. In older instruments, the handle is part of the frame, and looks like a mere strut. A student once made a sextant for a class that I taught, and did not include a handle at all for there were none in the explanations or specimen photographs that he had consulted: the source documents were all about angles and optics, and sextants he saw in museum displays and photographs were oriented with the handle towards the floor or back wall because the eye-catching, skill-communicating, wonder-inspiring side carries the engravings and optics. When sextants and octants are shown in use, the handle tends to be oriented away from the viewer, and covered by the operator’s hand.

The handle, of course, is important. One hand goes on the handle, so operators can align their eyes with the eyepiece, and have the other hand free to swing the instrument’s arm. When the instrument is used correctly, the handle is definitely a handle, and it is in just the right place. This insight can be developed by extending the analysis from a hand–handle connection to a whole-body interpretation that brings hands and eye into play along

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10. The first iteration of this course – directed primarily towards establishing historical scientific instruments as primary sources in the history of science – is described in Alistair Kwan, “Determining historical practises through critical replication: A classroom trial”, Rittenhouse 22 (2010), pp. 132–151.

Figure 4: Sextant and its use in a twentieth-century diagram emphasising the angle measurement. Clyde Fisher, John Hiram Gerould and James Plummer Poole, The Marvels and Mysteries of Science, W.H. Wise & Co., New York, 1941, p. 128, fig. 10

Figure 5: Sextant and its use in a late nineteenth-century depiction. A. Guillemi, El mundo físico, Montaner y Simón, Barcelona, 1883, v. 2, p. 208, fig. 213
with the arms, neck, head and torso between them. That whole-body, whole-instrument interpretation can be prompted by questions such as the following: (24)

- Where would your arm fit?
- Would you sit or stand – would it be different on land, versus a listing ship?
- What if you held it differently – maybe it’s upside-down or sideways?
- For how long could you work like that? How would your body feel?

In my classes, the embodied approach shifted an astrolabe from being perceived as a geometric projection and decorative fretwork to a purposefully heavy object that hangs on a finger or thumb or hook, while you sight stars or spires along its alidade. This shift is doubly meaningful, for it shows that there are in fact two useful ways to hold astrolabes: in an edge-on orientation for measuring, and a flat-facing orientation for calculating and admiring. Astrolabes hence switch automatically between two modes according to their connection with the operator’s body – a precedent for what today’s gadget industry calls “context-aware functionality.”

An embodied approach can likewise shift an observing couch from a luxurious venue where gentleman-astronomers lie back to ponder the mysteries of the heavens, to practical relief from the backbreaking, neck-crunching, knee-grinding labour of timing meridian transits without one (Fig. 6). The long telescope control rods can seem unnecessary or inconveniently located for an observer standing up, but make perfect sense for an observer restricted to a couch. On the other hand, sometimes there is no good space for a couch. An optical elbow – a reflector (usually a prism) mounted so the eyepiece can attach perpendicularly to the telescope’s axis – saves the astronomer’s neck. At other times, there is no aid at all: the astronomer is simply uncomfortable. What might that let our students inquire about the nature of the work? Perhaps the measurements were confined to short periods that the astronomer could endure. Perhaps several observers took shifts to share the burden. Perhaps discomfort was a trade-off to minimise the carriage of equipment to a remote or dangerous field site (Fig. 7). Or perhaps astronomers are a bit tougher and more hands-on than those stereotyped gentleman observers who lie back beneath the starry sky to dream of queen and cosmos.

In the same way, a spinthariscope (Fig. 8) shifts from being a philosophical amusement to a demand for long, careful concentration, a good posture to avoid a stiff back or neck, and a relaxed face (both eyes open, perhaps one of them covered with a black eyepatch) to avoid cramps. Ernest Rutherford’s nuclear model of the atom shifts from originating in a graph of scattering distributions to a careful process of staring fixedly into that tiny lens in front of the phosphorescent screen for a whole minute or two before taking a break, and all that only after thirty minutes of waiting for the eye to adapt to the darkened laboratory so that the faint flashes could be seen at all. What did the laboratory spinthariscope even look like? Research articles generally show only a schematic (Fig. 8, bottom left), not the actual object in use.11

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11. H. Geiger and E. Marsden, “On a Diffuse Reflection of the α-Particles”, Proceedings of the Royal Society A
Figure 6: Equatorial telescope at Greenwich. Leisure Hour 525, Jan. 10, 1862, p. 40
Figure 7: Zenith telescope in the field. Canada Dept. of Mines and Technical Surveys / Library and Archives Canada / PA-019667
Spinthariscope illustrations tend to show the 'toy' form, emphasising either theory (top left) or amusement (right). As research documentation is typically schematic (bottom left), the screen's form, affordances and use must be deduced from extant objects and descriptions. Respectively from: Scientific American 91 (1904), p. 428; Dundee Evening Post, 10 December 1903, © The British Library Board, used with permission via the British Newspaper Archive; H. Geiger and E. Marsden, "On a Diffuse Reflection of the α-Particles", Proceedings of the Royal Society A 82 (1909), p. 496.
As these cases suggest, an embodied interpretation process, developed through design theory, has potential to lead learners towards readings radically different from the formalist, stylistic, mathematical and theoretical readings more usual in science and history of science, and can fill out the “would have” statements that can otherwise want for explicit justification: a plausible justification for “they would have” may be as simple as, “Let’s all try standing like that for ten minutes to see how it feels”, given a classroom encultured to work with such ways of knowing. Interpretations could be expressed through models or mannequins or drawings in which human figures communicate the relationships between instrument and operator and environment, thus complementing ideas that can be expressed naturally in text. Such discussion would centre on empirical practice, offering a perspective on history of science, technology and medicine that complements the more usual attention to theoretical concepts by adding different kinds of knowing, struggle, patience, cost, technical complication and expertise.

4 Design Analysis, Material Culture, and Historiography

Material culture theories have tended to emphasise the visible content of objects. That tendency is understandable: epistemic culture, indeed human nature, skews heavily towards the visible. As Aristotle noted long ago, we learn through sight above all other senses, a preference echoed in modern metaphor: we understand by ‘seeing’ and ‘getting the picture’, we gain ‘clarity’ when ‘illuminated’ by ‘lucid’ or ‘transparent’ explanations that ‘elucidate’ or ‘shine light upon’ the ‘opaque’, the ‘obscure’, the ‘darkness’, hence ‘lifting the veil’, or ‘clearing the fog’. Subtlety and context are ‘perspective’ and, in the pretentious patois of government and business, bias and spin-doctoring are ‘optics’. Scarce are metaphors that connect scientific knowing with other senses, though there are a few associated with haptic interaction: ‘to grasp’, ‘to fathom’, and some intuitive and emotional knowing through sensations in the throat, stomach, and limbs. That same visual tendency occurs, naturally, in the canonical studies underlying material culture method. For example, E. McClung Fleming’s court cupboard study (which established the Winterthur protocol) relates an object’s visible features to cultural context, but underplays the actions of opening the cupboard doors and putting things inside it. Craig Gilborn’s Coke-bottle study similarly

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82 (1909), pp. 495–500: p. 496.
focusses on the visible, even though much of Coca-Cola’s advertising evokes the haptic –
cold curved glass wet with condensation, held in the hand and pressed against the lips –
and includes the auditory – the iconic sound of gas escaping from a freshly opened bottle.
Jules Prown’s teapot study\textsuperscript{15} concentrates mostly on visible shape, and from here speculates
about how the object might feel, in order to deduce the functions of the teapot’s belly,
handle, lid and spout. Like Gilborn’s study, Grant McCracken’s study of clothing\textsuperscript{16} brings
us from high culture to popular culture, while cautioning us about the language of
visible matter: conservative codes are relatively readable because they follows stiff rules,
but innovative codes, especially the fashion codes of subcultural rebellions, can be very
hard for an outsider to make sense of. When looking back at past fashions (including
fashions that shaped scientific instruments), we can be misled by the simple reason of
having lost the language or code of an otherwise little-documented subculture (for example,
that of laboratory scientists or Arts and Crafts machinists), applying today’s conventions
or text-documented norms with no easy way to detect their inapplicability.

Material culture readings rely also on connoisseurship and perceptiveness. Scientific
instrument connoisseurship, like every other kind, comes but slowly, and few have the
opportunity to develop it. As for perceptiveness, we may fear for its continuing diminution
as society, and in particular formal schooling, leans persistently towards knowledge that
can be handled by computers and delivered through words and simple diagrams alone.
Design analysis offers a way to bring perceptiveness back to the fore, echoing and extending
the descriptive phases of Prown’s and Fleming’s approaches, and making them accessible
to novice learners by embracing more senses and the kinds of non-visual knowledge that
the full range of senses provides access to.

By expanding description from visual and geometric to embrace the haptic and proprioceptive,
design analysis can broaden material culture readings to shift the historiographic
positioning of historical instruments in (at least) three important ways.

First, INSTRUMENTS BECOME EVIDENCE. Rather than slotting available objects into text-driven narratives, learners are called to read the instruments directly for themselves, to find and construct their own meanings. Because practical issues such as bodily comfort and specific skill needs are documented only very lightly in the textual record, there is little opportunity or temptation to look up what someone else claimed about it: the instrument may be the only extant source at hand, or the only extant source at all. The instrument becomes a potential source of tacit knowledge.\textsuperscript{17} Tacit knowledge is essential to a comprehensive understanding: as Michael Polanyi put it, in his consideration of how

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perception drives knowing, “A wholly explicit knowledge is unthinkable.” The knowledge that I am after here, though, is made tacit through more than not being said: it is not even sayable. There are no words for it, no notation by which it is systematically expressed. Such non-codable knowledge matters, and a surprising amount can be experienced by approaching the object in a non-linguistic way.

Having construed the object as its own evidence for itself, learners have good reason to check catalogues of other collections for corroborating specimens or counterexamples. My own students found this process frustrating, as they discovered that photographs nearly always showed instruments from a standardised view (e.g. very few museum astrolabe catalogue entries show the astrolabes’ sights), and with an overall emphasis on pristine or restored exemplars that show no evidence of wear or adaptation or usage context. That frustration was actually helpful: it showed them how documentation and evidence survival are often determined by the questions being asked at the time of collection, and by cultural value systems that prescribe what and whose evidence counts as ‘significant’. While these biases might be considered blinkered, they can be recast as the primary evidence of collection formation processes and of historiographic considerations that learners commonly find too abstract or irrelevant, but are here made meaningful by direct engagement.

Positioning instruments as evidence can also help students to understand texts. I once asked a class to tell me about the scarificators that they had been reading about in the context of therapeutic bloodletting. After a few minutes of hearing their thoughts, I opened a box. As they beheld the scarificator inside, I asked, “Is this what you were imagining?” Not one of them had imagined anything like it. I slowly cocked the spring and pressed the release. Most jumped when they heard the mechanism snap; the blades moved so quickly that half of them didn’t see it happen. They hadn’t imagined this, either. They saw how clumsily I held the device, and none wanted to try it themselves, fearful of slipping. “Does anyone want to volunteer an arm to see how cleanly it cuts?” They recoiled. Visceral imagination had, in only a few minutes of non-codable knowledge, transfigured what they had read, much as Polanyi declared: “...what the pupil must discover by an effort of his own is something we could not tell him. And he knows it in turn but cannot tell it.”

A second historiographic shift is that scientific practice becomes bodily practice. As much as curricula exhort the teaching of science as process, and as an interplay between conceptualisation and evidence and socio-cultural forces, science textbooks, histories of science, and university science education all hold experimentation down in a supporting role. Experiments are typically mentioned as accidents providing serendipitous discovery (for example, the Stern–Gerlach experiment, William Crookes’ invention of the spinthariscope), confirmations of an idea (for example, Galileo dropping balls off the

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19. Analogous problems occur also in the history of music, where the materiality of instruments and their relationships with performers’ bodies is little-studied: see Nicholas Cook, *Beyond the Score: Music as Performance*, Oxford University Press, New York, 2013.
Pisan Leaning Tower, Arthur Eddington measuring the deflection of starlight), or as an ingenious technique (for example, Fizeau’s and Foucault’s methods for measuring the speed of light). As with the sextant mentioned earlier, however, we seldom read much about the practicalities of actually performing these experiments; they are typically described only in passing. That streamlined portrayal is echoed in science classrooms – witness, for example, the mass-produced torsion balances for measuring Coulomb’s Law. While history of science can approach replication with a clearly historical purpose, overall it finds practical science elusive – what evidence does doing leave behind? Design analysis offers a way to bring some of the experimental process and tacit practical knowledge back into play, and to interrogate what is meant by words such as “skill” and “technique”. In particular, design analysis gives opportunity to consider how a good deal of tacit knowledge comes through difficulty and discomfort. An operator’s discomfort may drive improvement towards fluent action (that is, critical practice to hone skills), or alternatively to stoicism and stamina. As music, dance, and trades educators are well aware, however, uncritical repetition can also lead to the learning of bad habits.

Within the practical-science culture of doing and experiencing there lies a third shift: a profound humanisation of scientific instruments. Design analysis expands the cultural scope in which historic instrumentation can be contextualised. Adding to the practical culture of doing, and the visual culture of appreciation, and the intellectual culture of natural and mathematical learning, design analysis takes us to the individual human element of bodily engagement, of visceral experience, and of that ancient question of how our senses and other bodily capacities restrict – or determine – human access to Nature’s deep truths. Do we really perceive truth, whether directly (recall Plato’s cave and the Renaissance pyrrhonists) or through mediating instrumentation (early opposition to the telescope)? Can we truly share observations (hence the solar microscope and self-registering instrumentation)? Can others replicate our results (hence the personal equation for astronomical timings)? What limitations in the mind–body–instrument–nature complex can be addressed through design? Design directly links individual humans with the knowledge that those humans comprehend and produce. Both the body-imagination inquiries described above, and historical replication methods, can thus be given clearer purpose – whether didactic or historiographic – through explicit design analysis.

5 Design Analysis and the Museum in the Curriculum and Pedagogy

To absorb and rehearse pre-processed information is not enough: as John Dewey argued, learners must experience knowledge, and that experience must be more than the kind that pads a curriculum vitae, but an intellectually engaging kind, an experience that transforms
Experience features strongly in early childhood education, where curriculum involves all of the senses and integrates psychomotor and affective learning with the cognitive. As children age, the curricular balance shifts towards the cognitive alone, towards words and symbols and abstracts. We welcome abstraction as intellectual maturation, but may not notice what broad swathes of knowledge are excluded by abandoning the emotional and sensory. The knowledge lost is not simply ‘it makes my fingers hurt’, but a far more consequential loss in the range and depth of cognitive engagement: higher education exhibits a damming comfort with the lowest levels of Benjamin Bloom's taxonomy, far short of the critical thinking and citizenship that curricula and institutional vision statements widely champion.

An embodied analysis of design can help to restore what Edward Reed, following Dewey, calls ‘the information – termed ecological – that all human beings acquire from their environment by looking, listening, feeling, sniffing, and tasting – the information, in other words, that allows us to experience things for ourselves.’ It matters because, as Dewey put it, “We never educate directly, but indirectly by means of the environment. Whether we permit chance environments to do the work, or whether we design environments for the purpose makes a great difference.” Obviously, designing the learning environment entails attention to multiple sensory factors, and sensory factors must, by necessity, feature in any complete understanding instruments made for sensory use. Reed argues for more: ecological information is essential to realising individual and communal human potential, for it connects us with our contexts, freedoms and constraints. We need ecological information to tackle the age-old question, “How should I live?” Historical scientific instruments, with their close ties to how we understand and conceptualise the world in which we exercise our free agency and communal contribution, may be a good entry-point for knowledge-experiences of especially worthwhile kinds.

Design analysis will not work for all kinds of instruments, nor for all kinds of science.


But, like palaeography and textual criticism, it does offer a starting-point for direct historical inquiry. It is not blocked by mathematical anxiety, bad experiences with cursive handwriting, nor by not knowing Arabic, Chinese, Sanskrit and Latin. It does not exclude cultures whose knowledge is not written. Design analysis offers museums and historical instrumentation collections a special educational role that textbooks, lectures, and lecture slides cannot cover.