again and again, by contrast, enables self-criticism. Modern education fears repetitive learning as mind-numbing. Afraid of boring children, avid to present ever-different stimulation, the enlightened teacher may avoid routine—but thus deprives children of the experience of studying their own ingrained practice and modulating it from within.

Skill development depends on how repetition is organized. This is why in music, as in sports, the length of a practice session must be carefully judged: the number of times one repeats a piece can be no more than the individual's attention span at a given stage. As skill expands, the capacity to sustain repetition increases. In music this is the so-called Isaac Stern rule, the great violinist declaring that the better your technique, the longer you can rehearse without becoming bored. There are "Eureka!" moments that turn the lock in a practice that has jammed, but they are embedded in routine.

As a person develops skill, the contents of what he or she repeats change. This seems obvious: in sports, repeating a tennis serve again and again, the player learns to aim the ball different ways; in music, the child Mozart, aged six and seven, was fascinated by the Neapolitan-sixth chord progression, in fundamental position (the movement, say, from a C-major chord to an A-flat major chord). A few years after working with it, he became adept in inverting the shift to other positions. But the matter is also not obvious. When practice is organized as a means to a fixed end, then the problems of the closed system reappear; the person in training will meet a fixed target but won't progress further. The open relation between problem solving and problem finding, as in Linux work, builds and expands skills, but this can't be a one-off event. Skill opens up in this way only because the rhythm of solving and opening up occurs again and again.

These precepts about building skill through practice encounter a great obstacle in modern society. By this I refer to a way in which machines can be misused. The "mechanical" equates in ordinary language with repetition of a static sort. Thanks to the revolution in micro-

computing, however, modern machinery is not static; through feedback loops machines can learn from their experience. Yet machinery is misused when it deprives people themselves from learning through repetition. The smart machine can separate human mental understanding from repetitive, instructive, hands-on learning. When this occurs, conceptual human powers suffer.

Since the Industrial Revolution of the eighteenth century, the machine has seemed to threaten the work of artisan-craftsmen. The threat appeared physical; industrial machines never tired, they did the same work hour after hour without complaining. The modern machine's threat to developing skill has a different character.

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An example of this misuse occurs in CAD (computer-assisted design), the software program that allows engineers to design physical objects and architects to generate images of buildings on-screen. The technology traces back to the work of Ivan Sutherland, an engineer at the Massachusetts Institute of Technology who in 1963 figured out how a user could interact graphically with a computer. The modern material world could not exist without the marvels of CAD. It enables instant modeling of products from screws to automobiles, specifies precisely their engineering, and commands their actual production.[25] In architectural work, however, this necessary technology also poses dangers of misuse.

In architectural work, the designer establishes on screen a series of points; the algorithms of the program connect the points as a line, in two or three dimensions. Computer-assisted design has become nearly universal in architectural offices because it is swift and precise. Among its virtues is the ability to rotate images so that the designer can see the house or office building from many points of view. Unlike a physical model, the screen model can be quickly lengthened, shrunk, or broken into parts. Sophisticated applications of CAD model the effects on a structure of the changing play of light, wind, or seasonal temperature change. Traditionally, architects have analyzed solid buildings in two ways, through plan and section. Computer-assisted design permits many other forms of analysis, such as taking a mental journey, on-screen, through the building's airflows.

How could such a useful tool possibly be abused? When CAD first entered architectural teaching, replacing drawing by hand, a young architect at MIT observed that "when you draw a site, when you put in the counter lines and the trees, it becomes ingrained in your mind. You come to know the site in a way that is not possible with the computer. . . . You get to know a terrain by tracing and retracing it, not by letting the computer 'regenerate' it for you."[26] This is not nostalgia: her observation addresses what gets lost mentally when screen work replaces physical drawing. As in other visual practices, architectural sketches are often pictures of possibility; in the process of crystallizing and refining them by hand, the designer proceeds just as a tennis player or musician does, gets deeply involved in it, matures thinking about it. The site, as this architect observes, "becomes ingrained in the mind."

The architect Renzo Piano explains his own working procedure thus: "You start by sketching, then you do a drawing, then you make a model, and then you go to reality—you go to the site—and then you go back to drawing. You build up a kind of circularity between drawing and making and then back again."[27] About repetition and practice Piano observes, "This is very typical of the craftsman's approach. You think and you do at the same time. You draw and you make. Drawing . . . is revisited. You do it, you redo it, and you redo it again."[28] This attaching, circular metamorphosis can be aborted by CAD. Once points are plotted on-screen, the algorithms do the drawing; misuse occurs if the process is a closed system, a static means-end—the "circularity" of which Piano speaks disappears. The physicist Victor Weisskopf once said to his MIT students who worked exclusively with computerized

experiments, "When you show me that result, the computer understands the answer, but I don't think you understand the answer."[29]

Computer-assisted design poses particular dangers for thinking about buildings. Because of the machine's capacities for instant erasure and refiguring, the architect Elliot Felix observes, "each action is less consequent than it would be [on] paper . . . each will be less carefully considered."[30] Returning to physical drawing can overcome this danger; harder to counter is an issue about the materials of which the building is made. Flat computer screens cannot render well the textures of different materials or assist in choosing their colors, though the CAD programs can calculate to a marvel the precise amount of brick or steel a building might require. Drawing in bricks by hand, tedious though the process is, prompts the designer to think about their materiality, to engage with their solidity as against the blank, unmarked space on paper of a window. Computer-assisted design also impedes the designer in thinking about scale, as opposed to sheer size. Scale involves judgments of proportion; the sense of proportion on-screen appears to the designer as the relation of clusters of pixels. The object on-screen can indeed be manipulated so that it is presented, for instance, from the vantage point of someone on the ground, but in this regard CAD is frequently misused: what appears on-screen is impossibly coherent, framed in a unified way that physical sight never is.

Troubles with materiality have a long pedigree in architecture. Few large-scale building projects before the industrial era had detailed working drawings of the precise sort CAD can produce today; Pope Sixtus V remade the Piazza del Popolo in Rome at the end of the sixteenth century by describing in conversation the buildings and public space he envisioned, a verbal instruction that left much room for the mason, glazier, and engineer to work freely and adaptively on the ground. Blueprints—inked designs in which erasure is possible but messy—acquired legal force by the late nineteenth century, making these images on paper equivalent to a lawyer's contract. The blueprint signaled, moreover, one decisive disconnection between head and hand in design: the idea of a thing made complete in conception before it is constructed.

A striking example of the problems that can ensue from mentalized design appear in Georgia's Peachtree Center, perched on the edge of Atlanta. Here is to be found a small forest of concrete office towers, parking garages, shops, and hotels, edged by highways. As of 2004, the complex covered about 5.8 million square feet, which makes this one of the largest "megaprojects" in the region. The Peachtree Center could not have been made by a group of architects working by hand—it is simply too vast and complex. The planning analyst Bent Flyvbjerg explains a further economic reason why CAD is necessary for projects of this scope: small errors have large knock-on effects.[31]

Some aspects of the design are excellent. The buildings are laid out in a grid plan of streets forming fourteen blocks rather than as a mall; the complex pays allegiance to the street and is meant to be pedestrian friendly. The architecture of the three large hotels is by John Portman, a flamboyant designer who favors such dramatic touches as glass elevators running up and down forty stories of interior atriums. Elsewhere, the three trade marts and office towers are more conventional concrete-and-steel boxes, some faced outside with the Renaissance or Baroque detailing that has become the stamp of postmodern design. The project as a whole reaches for character rather than anonymity. Still, pregnant failures of this computer-driven project are evident on the ground—three failures that menace computer-assisted design more largely as a disembodied design practice.

The first is the disconnect between simulation and reality. In plan, the Peachtree Center populates the streets with well-designed sidewalk cafés. Yet the plan has not actually engaged with the intense Georgia heat: the outdoor seats of the cafés are in fact empty from late morning to late afternoon much of the year. Simulation is an imperfect

substitute for accounting the *sensation* of light, wind, and heat on site. The designers would perhaps have done better to sit unprotected in the midday Georgia sun for an hour before going to work each day; physical discomfort would have made them see better. The large issue here is that simulation can be a poor substitute for tactile experience.

Hands-off design also disables a certain kind of relational understanding. Portman's hotel, for instance, emphasizes the idea of coherence, with its inner drama of all-glass elevators running up a forty-story atrium; the hotel's rooms look outward over parking lots. On-screen, the parking-lot issue can be put out of mind by rotating the image so that the sea of cars disappears; on foot, it cannot be disposed of in this way. To be sure, this is not the computer's inherent fault. Portman's designers could perfectly well have put in an image of all the cars and then viewed the sea, on-screen, from the hotel rooms, but then they'd have had a fundamental problem with the design. Whereas Linux is set up to discover problems, CAD is often used to hide them. The difference accounts for some of CAD's commercial popularity; it can be used to repress difficulty.

Finally, CAD's precisions bring out a problem long inherent in blueprint design, that of overdetermination. The various planners involved in the Peachtree Center rightly point with pride to its mixed-use buildings, but these mixtures have been calculated down to the square foot; the calculations draw a false inference about how well the finished object will function. Overdetermined design rules out the crinkled fabric of buildings that allow little start-up businesses, and so communities, to grow and vibrate. This texture results from underdetermined structures that permit uses to abort, swerve, and evolve. There is thus missing the informal and so easy, sociable street life of Atlanta's older neighborhoods. A positive embrace of the incomplete is necessarily absent in the blueprint; forms are resolved in advance of their use. If CAD does not cause this problem, the program sharpens it: the algorithms draw nearly instantly a totalized picture.

The tactile, the relational, and the incomplete are physical experiences that occur in the act of drawing. Drawing stands for a larger range of experiences, such as the way of writing that embraces editing and rewriting, or of playing music to explore again and again the puzzling qualities of a particular chord. The difficult and the incomplete should be positive events in our understanding; they should stimulate us as simulation and facile manipulation of complete objects cannot. The issue—I want to stress—is more complicated than hand *versus* machine. Modern computer programs can indeed learn from their experience in an expanding fashion, because algorithms are rewritten through data feedback. The problem, as Victor Weisskopf says, is that people may let the machines do this learning, the person serving as a passive witness to and consumer of expanding competence, not participating in it. This is why Renzo Piano, the designer of very complicated objects, returns in a circular fashion to drawing them roughly by hand. Abuses of CAD illustrate how, when the head and the hand are separate, it is the head that suffers.

Computer-assisted design might serve as an emblem of a large challenge faced by modern society: how to think like craftsmen in making good use of technology. "Embodied knowledge" is a currently fashionable phrase in the social sciences, but "thinking like a craftsman" is more than a state of mind; it has a sharp social edge.

Immured in the Peachtree Center for a weekend of discussions on "Community Values and National Goals," I was particularly interested in its parking garages. A standardized bumper had been installed at the end of each car stall. It looked sleek, but the lower edge of each bumper was sharp metal, liable to scratch cars or calves. Some bumpers, though, had been turned back, on site, for safety. The irregularity of the turning showed that the job had been done manually, the steel smoothed and rounded wherever it might be unsafe to touch; the craftsman had thought for the architect. The lighting in these aboveground car-houses turned out to be uneven in intensity, dangerous shadows suddenly appearing within the building. Painters had added odd-shaped white strip lines to guide drivers in and out of irregular pools of light, showing signs of improvising rather than following the plan. The craftsmen had done further, deeper thinking about light than the designers.

These steel grinders and painters had evidently not sat in on design sessions at the start, using their experience to indicate problematic spots in the designs plotted on-screen. Bearers of embodied knowledge but mere manual laborers, they were not accorded that privilege. This is the sharp edge in the problem of skill; the head and the hand are not simply separated intellectually but socially.

Conflicting Standards

Correct versus Practical

What do we mean by good-quality work? One answer is how something should be done, the other is getting it to work. This is a difference between correctness and functionality. Ideally, there should be no conflict; in the real world, there is. Often we subscribe to a standard of correctness that is rarely if ever reached. We might alternatively work according to the standard of what is possible, just good enough—but this can also be a recipe for frustration. The desire to do good work is seldom satisfied by just getting by.

Thus, following the absolute measure of quality, the writer will obsess about every comma until the rhythm of a sentence comes out right, and the woodworker will shave a mortise-and-tenon joint until the two pieces are completely rigid, needing no screws. Following the measure of functionality, the writer will deliver on time, no matter that every comma is in place, the point of writing being to be read. The functionally minded carpenter will curb worry about each detail, knowing that small defects can be corrected by hidden screws. Again, the point is to finish so that the piece can be used. To the absolutist in every craftsman, each imperfection is a failure; to the practitioner, obsession with perfection seems a prescription for failure.

A philosophical nicety is necessary to bring out this conflict. *Practice* and *practical* share a root in language. It might seem that the more people train and practice in developing a skill, the more practical minded they will become, focusing on the possible and the particular. In fact, the long experience of practice can lead in the opposite direction. Another variant of the "Isaac Stern rule" is: the better your technique, the more impossible your standards. (Depending on his mood, Isaac Stern worked many, many variations of the "Isaac Stern rule" on the virtue of repeated practice.) Linux can operate in a similar fashion. The people most skilled in using it are usually the ones thinking about the program's ideal and endless possibilities.

The conflict between getting something right and getting it done has today an institutional setting, one I shall illustrate in the provision of medical care. Many elderly readers will, like me, know only too well its outline.

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In the past decade Britain's National Health Service (NHS) has had new measures for determining how well doctors and nurses do their jobs—how many patients are seen, how quickly patients have access to care, how efficiently they are referred to specialists. These are numeric measures of the right way to provide care, but measures meant to serve patient interests humanely. It would be easier, for instance, if referral to specialists was left to the doctor's convenience. However, doctors as well as nurses, nurses' aides, and cleaning staff believe that these "reforms" have diminished the quality of care, using the guideline of what's practicable on the ground. Their sentiments are hardly unusual. Researchers in western Europe widely report that practitioners believe that their craft skills in dealing with patients are being frustrated by the push for institutional standards.

The National Health Service has a special context quite unlike American-style "managed-care" or other market-driven mechanisms. In the wake of the Second World War, the creation of the NHS was a source of national pride. The NHS recruited the best people, and they were committed; few departed for better-paying jobs in America. Britain has spent a third less of its gross domestic product on health than the United States, yet its infant mortality rate is lower, and its elderly live longer. The British system is "free" health care, paid for through taxes. The British people have indicated that they are happy to pay these taxes, or even contribute more, if only the service can improve.

In time, like all systems, the NHS has worn down. The hospitals physically aged, equipment needing replacement remained in use, waiting times for service lengthened, and not enough nurses were in training. To solve these ills, Britain's politicians turned a decade ago to a different model of quality, one established by Henry Ford in the American auto industry early in the twentieth century. "Fordism" takes the division of labor to an extreme: each worker does one task, measured as precisely as possible by time-and-motion studies; output is measured in terms of targets that are, again, entirely quantitative. Applied to health care, Fordism monitors the time doctors and nurses spend with each patient; a medical treatment system based on dealing with auto parts, it tends to treat cancerous livers or broken backs rather than patients in the round.[32] A particular wrinkle in British health care is the number of times the health service has been "reformed" along Fordist lines in the past decade: four major reorganizations reverse or depart from previous changes.

Fordism has acquired a bad name in private industry for reasons that Adam Smith first laid out in *The Wealth of Nations* in the eighteenth century. The division of labor focuses on parts rather than wholes; to the vivacity of merchants, Smith contrasted the dulled wits of factory laborers doing just one small thing, hour after hour, day after day. Smith believed, though, that this system would be more efficient than work done by hand in the preindustrial way. Henry Ford justified his procedures by arguing that strictly machine-built autos were of better quality than those cars that were in his time assembled in small workshops. The advent of microelectronics in manufacturing has provided further support for this way of making things: microsensors do a much more rigorous, steady job of monitoring problems than human eyes or hands. In sum, by the absolute measure of quality in the thing itself, the machine is a better craftsman than a person.

Medical reform finds its place in this long debate about the nature and value of craftsmanship in a mechanical, quantitative society. In the NHS, the Fordist reformers can claim quality has indeed improved: in particular, cancers and heart diseases are better treated. Moreover, frustrated though they are, British doctors and nurses have not lost the will to do good work; theirs is not the story of the Soviet construction workers. Though fatigued by constant reform and angry at the system of targets, these health care providers have not become indifferent to doing high-quality work; Julian Legrand, an insightful analyst of the NHS, remarks on the fact that although staff are nostalgic for the old days of loose practice, if they were magically transported back two generations, they would be appalled by what they saw.[33]

Putting nostalgia aside, what is there about medical "craft" that is demeaned by these changes? Studies of nurses provide one answer.[34] In the "old" NHS, nurses listened to elderly patients' stories about their children as well as to complaints about aches and pains; in the hospital wards, nurses often stepped in when a patient crisis erupted, even if they were legally not qualified to do so. Obviously, a sick patient cannot be repaired like an automobile, but behind this stands a deeper point about the practice standard. To do good work means to be curious about, to investigate, and to learn from ambiguity. As with Linux programmers, nursing craft negotiates a liminal zone between problem solving and problem finding; listening to old men's chatter, the nurse can glean clues about their ailments that might escape a diagnostic checklist.

This liminal zone of investigation is important to doctors in another way. In the Fordist model of medicine, there must be a specific illness to treat; the evaluation of a doctor's performance will then be made by counting the time required to treat as many livers as possible and the number of livers that get well. Because bodily reality doesn't fit well inside this classifying model, and because good treatment has to admit experiment, a not insignificant number of doctors create paper fictions to buy themselves time from the bureaucratic monitors. Doctors in the NHS often assign a patient a disease in order to justify the time spent on exploring a puzzling body.

The absolutists working on standards for the system can claim that they've raised the quality of care. Nurses and doctors in practice argue against this numeric claim. Rather than fuzzy sentimentalism, they invoke the need for curiosity and experiment and would subscribe, I think, to Immanuel Kant's image of "the twisted timber of humanity" as applying to both patients and themselves.

This conflict came to a head on June 26, 2006, at the annual meeting of the British Medical Association in Belfast. The association's president, Dr. James Johnson, observed that the government's "favored method of raising quality and keeping prices down is to do what they do in supermarkets and offer choice and competition." To his colleagues he said, "You tell me that the breakneck pace and incoherent planning behind systems reform are seriously destabilising the NHS. The message I am getting from the medical profession is that the NHS is in danger and that doctors have been marginalised." To the government, Johnson appealed, "Work with the profession. We are not the enemy. We will help you find the solution."[35] When government officials then took the stage, however, an icy, polite silence greeted their speeches.

British doctors and nurses are today suffering from reform fatigue, an NHS decisively reformed several times in a decade. Any organizational reform takes time to "bed in"; people have to learn how to put the changes into practice—whom now to call, which forms to use, what procedures to follow. If a patient is having a heart attack, you do not want to reach for your "Manual of Best-Practice Performances" to discover the latest rules about what you are supposed to do. The process of bedding in takes longer the bigger and more complex the organization in which one works. The NHS, Britain's biggest employer, consists of more than 1.1 million people. It cannot turn like a sailboat. Both nurses and doctors are still learning the changes proposed a decade ago.

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Embedding stands for a process essential to all skills, the conversion of information and practices into tacit knowledge. If a person had to think about each and every movement of waking up, she or he would take an hour to get out of bed. When we speak of doing something "instinctively," we are often referring to behavior we have so routinized that we don't have to think about it. In learning a skill, we develop a complicated repertoire of such procedures. In the higher stages of skill, there is a constant interplay between tacit knowledge and self-conscious awareness, the tacit knowledge serving as an anchor, the explicit awareness serving as critique and corrective. Craft quality emerges from this higher stage, in judgments made on tacit habits and suppositions. When an institution like the NHS, in churning reform, doesn't allow the tacit anchor to develop, then the motor of judgment stalls. People have no experience to judge, just a set of abstract propositions about good-quality work.

Proponents of absolutist standards of quality, however, have many worries about the interchange between tacit and explicit knowledge—as long ago as in Plato's writings on craftsmanship, the experiential standard is treated with suspicion. Plato views it as too often an excuse for mediocrity. His modern heirs in the NHS wanted to root out embedded knowledge, expose it to the cleansing of rational analysis—and have become frustrated that much of the tacit knowledge nurses and doctors have acquired is precisely knowledge they cannot put into words or render as logical propositions. Michael Polanyi, the modern philosopher most attuned to tacit knowledge, has recognized the justice of this worry. Bedded in too comfortably, people will neglect the higher standard; it is by arousing self-consciousness that the worker is driven to do better.

Here, then, is an emblematic conflict in measures of quality, from which follow two different concepts of institutional craftsmanship. To take a generous view, the reformers of the NHS are crafting a system that works correctly, and their impulse to reform reflects something about all craftsmanship; this is to reject muddling through, to reject the job just good enough, as an excuse for mediocrity. To take an equally generous view of the claims of practice, it encompasses pursuing a problem—be it a disease, a bumper railing, or a piece of the Linux computer kernel—in all its ramifications. This craftsman must be patient, eschewing quick fixes. Good work of this sort tends to focus on relationships; it either deploys relational thinking about objects or, as in the case of the NHS nurses, attends to clues from other people. It emphasizes the lessons of experience through a dialogue between tacit knowledge and explicit critique.

Thus, one reason we may have trouble thinking about the value of craftsmanship is that the very word in fact embodies conflicting values, a conflict that in such institutional settings as medical care is, so far, raw and unresolved.

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An ancient ideal of craftsmanship, celebrated in the hymn to Hephaestus, joined skill and community. Traces of that ancient ideal are still evident today among Linux programmers. They seem an unusual, marginal group because of three troubled ways in which craftsmanship is now organized.

The first trouble appears in the attempts of institutions to motivate people to work well. Some efforts to motivate good work for the sake of the group have proved hollow, like the degradation of Marxism in Soviet civil society. Other collective motivations, like those in postwar Japanese factories, have succeeded. Western capitalism has sometimes claimed that individual competition rather than collaboration most effectively motivates people to work well, but in the high-tech realm, it is firms that enable cooperation who have achieved high-quality results.

A second trouble lies in developing skill. Skill is a trained practice; modern technology is abused when it deprives its users precisely of that repetitive, concrete, hands-on training. When the head and the hand are separated, the result is mental impairment—an outcome particularly evident when a technology like CAD is used to efface the learning that occurs through drawing by hand.

Third, there is the trouble caused by conflicting measures of quality, one based on correctness, the other on practical experience. These conflict institutionally, as in medical care, when reformers' desire to get things right according to an absolute standard of quality cannot be reconciled with standards of quality based on embedded practice. The philosopher finds in this conflict the diverging claims of tacit and explicit knowledge; the craftsman at work is pulled in contrary directions.

We can understand these three troubles better by looking more deeply into their history. In the next chapter we explore the workshop as a social institution that motivates craftsmen. Following that, we look at the eighteenth-century Enlightenment's first efforts to make sense of machines and skills. Last, we look at tacit and explicit consciousness in the long history of crafting a particular material.

CHAPTER TWO

The Workshop

The workshop is the craftsman's home. Traditionally this was literally so. In the Middle Ages craftsmen slept, ate, and raised their children in the places where they worked. The workshop, as well as a home for families, was small in scale, each containing at most a few dozen people; the medieval workshop looked nothing like the modern factory containing hundreds or thousands of people. It's easy to see the romantic appeal of the workshop-home to socialists who first confronted the industrial landscape of the nineteenth century. Karl Marx, Charles Fourier, and Claude Saint-Simon all viewed the workshop as a space of humane labor. Here they, too, seemed to find a good home, a place where labor and life mixed face-to-face.

Yet this beguiling image is misleading. The medieval workshop-home did not follow the rules of a modern family guided by love. Organized into a system of guilds, the workshop provided other, more impersonal emotional rewards, most notably, honor in the city. "Home" suggests established stability; this the medieval workshops had to struggle for, since they could not assume they would survive. The workshop as home may also obscure this living scene of labor today. Most scientific laboratories are organized as workshops in the sense that they are small, face-to-face places of work. So, too, can workshop conditions be