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Making technologies people don’t have to think about.

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Introduction

ACROSS THE TWO MILLION YEARS or so that human beings have been making and using tools, nothing prepared us for the dramatic changes wrought by the highly complex, integrated technologies that define today's computers and their associated communications components. I refer here, not to the broad social consequences of these marvels, but to the more immediate and specific relationship between human beings and the tools at hand—the points of interaction, the touch points. I have entitled this presentation "Making Technologies People Don't Have to Think About," and in doing so I am aiming to take my discussion toward the subject of design and interface and how these new technologies differ from our previous experiences with tools, and why now it is necessary to take a more integrated approach in their development.

Background

ALDOUS HUXLEY, writing in the 1950s, imagined a world in which "Science and technology would be used as though, like the Sabbath, they had been made for man, not (as at present…) as though man were to be adapted and enslaved to them." He penned these words thirty years after the publication of his famous novel *Brave New World* and a good twenty years before the appearance of digital computers. But I think many of us today, as we survey our desktops at work and at home—filled as they are with computers, modems, printers, scanners, fax machines, answering machines, and who knows what else—have reason to wonder if we aren't in fact slaves to a vast, ever-growing web of technology that renders us slightly less free and more harried than we were the day before. We find, in fact, that we are obliged to think about these technologies more often and at greater length than we would like, taking time away from the work we need to do and instead having to spend time learning the ins and outs of the latest system software or to discover what is making the computer freeze up every time we select the print command. The demands are many and almost continuous. We find ourselves having to read too many poorly written manuals and cumbersome how-to books, or spend too much time searching the Internet for FAQs or hot tips from computer support groups, or sitting too long by our telephones dialing a manufacturer's technical support number that may or may not answer. It matters to us little if the problems we are having arise from failures in the technology or from our own failure to understand the procedures necessary to operate them. Time wasted is time wasted, either way.

Moreover, all this stuff seems to be *morphing* as we sit here. There really is no time to learn what makes things tick. Most people who take the time to read about computers are familiar with that now-famous quote from Intel co-founder Gordon Moore. You know the one: it predicts that the speed of processors will double every two years. According to Moore himself the quote has developed a life of its own: it has acquired the force of law and has become a self-fulfilling prophecy that is gospel throughout the computer industry, driving the market in all things digital. "People know they have to stay on that curve to remain competitive, so they put the effort in to make it happen," he said in a recent interview with *Scientific American* magazine.

Not long ago I came across a cartoon in an anthropology journal that shows a cave man engaged in his work. He is unhurried and seems altogether content. He has only a handful of rather simple technologies at his side. None talk back, and they aren't the sort of things he has to spend much time thinking about. Our modern man, meanwhile, is curled into a ball and holding his head. Beside him his technological marvels chatter away, make demands, compete for his attention. Behind all such jokes there is always a grain of truth that reflects a genuine, and sometimes urgent, feeling of unease. It's not always clear that it is the technologies themselves that people are feeling uneasy about. Most people readily acknowledge the benefits that electronics, especially digital technologies, bring to their lives. Rather, I have the sense that the discomfort is more with the pace at which these technologies arrive and seemingly take charge of their lives in the way Huxley described, "as though man were to be adapted and enslaved to them." Everywhere they turn, the salesmen and pundits are there to remind them: "The Future is Now." And, of course, they have Moore's Law to prove it.

The Rate of Change

The future used to be *just* the future, of course, not very imposing, and always distant. As we look back across the two-million-year span that human beings have been making and using tools, we see that the rate of technological innovation remained rather flat, scarcely a blip on the radar screen, until about 7,000 years ago. That was when we began to settle down in large population centers, develop written languages, create systems of record keeping, and organize our agriculture and industrial production. It was only 2,500 years ago that we discovered iron and the process of smelting. And the mass printing of books, an innovation crucial in bringing us to where we are today with respect to our knowledge in science and technology, is only 550 years old. Consider further that it was only about 450 years ago that science and technology began to take the systematic form that we recognize today, which is also about the time that both the level of complexity of our tools and the rate of innovation began to increase at a measurable pace. It was still a manageable pace, however; people had plenty of time to absorb, to learn, and even to become skillful in the use of their tools. And the future was still tomorrow, next week, or next year, a distant horizon that we didn't have to think much about until it arrived.

It was really only a little more than 150 years ago—a mere blink of the eye—that our technological and scientific knowledge coalesced sufficiently to dramatically accelerate the rate of change. This was the birth of the machine age, and we saw a rapid succession of technological marvels that truly reshaped how people would live and work: steam power, photography, gas power, electricity, telephone and telegraph communications, adding machines, motion pictures, automobiles, air travel, mass production, television, jet propulsion, space travel, nuclear fission, advanced computational devices, and so on, multiplying almost faster than people could count. At the onset of the machine age people were simply in awe, taking it all in as if it were a show being put on by clever magicians. Science fiction literature was born during this phase of our history, and the names of people like Jules Verne and, a bit later, H.G. Wells, became household words.

Gradually, mass-produced commodities replaced hand-made goods. Unskilled labor was replaced by machines, while skilled labor took a pay cut. People began to feel more rushed, less in control of their lives, and more uncertain of their futures. They began to look at tools differently, seeing them less as instruments to extend their personal power and reach, and more as the instruments of industry in its quest for ever-increasing productivity and fatter profit margins. Science and technology became associated in the public mind with the invention of terrible weapons of mass destruction and the production of chemicals and other technologies that threaten our personal health as well as that of the planet.

I suppose we can say that the future stopped being the future around 1971. It's hard to believe, but this great burst of innovation we now call the digital revolution is only twenty-five years old. It has propelled human beings rather suddenly and without much preparation from that leisurely pace where the future was still tomorrow to the high-speed life of the technology-dependent digital age where the future is now—figuratively, if not in fact. The thought is jarring, and many of us are having a very hard time adjusting. Innovation has taken off in so many directions at once that we no longer keep score. The leap we are being asked to take, at least psychologically, is rather great. History has not prepared us for it. And, in some parts of the world, it is a bigger leap than for most of us. I fear we underestimate its cost in human terms, thinking all people are just like us.

My archaeologist wife told me a story about an island republic in the western Pacific where someone managed to bring a new four-by-four vehicle to an isolated village on one of the islands. But since there are no roads, and the village is surrounded by dense jungle, mangrove swamps, and taro patches, there is no place for the car to travel. It apparently caused upset among the people there. They couldn't decide who among them would drive it, or where they would go. And when they determined that the vehicle would need a continuous supply of fuel and oil, they decided it might be more trouble than it was worth. So they built a house for it that has neither doors nor windows. Now they don't have to think about it; out of sight, out of mind.

In many such places you'll find people whose lives have remained essentially unchanged for the past 1,500 to 2,000 years, and where change has occurred you'll find that the lines between the old and new are rather sharply drawn. Where yesterday the most efficient and reliable communications system was the small boat—at best, HAM radio—they are suddenly offered new choices. While the introduction of an automobile proved impractical in one place, in another place not far away you will find several Macintosh computers with modems, and you will discover that the people who use them have e-mail addresses, surf the Internet, consult the central government in matters of health and welfare, and communicate with family members who have gone abroad to study or work. Macs are very popular throughout the Pacific because they are easier to set up and operate than most other computer systems. About the only places you'll find PCs or other types of computer systems are in some government offices and in the offices of foreign engineering firms. Even with user-friendly computers, the leap these people are having to make, quite literally overnight, is nothing short of extraordinary. They are struggling, not only to learn how to use these machines, but also to fit themselves into the larger world that these machines open to them. In many of these island republics telephone service arrived only very recently, and things like e-mail and Internet access arrived only within the last year or so. Missing from most of these places are the support structures to help people use and maintain these technologies, something we take for granted.

Complexity and its Consequences

Along with the accelerating rate of change is an ever-increasing complexity of structure and function. We see multiple, integrated layers of this complexity piling upon more multiple, integrated layers. This layering has reached a point where it is now impossible for any one person to hold in their head the total knowledge necessary to produce that thing we call a computer and all of its associated devices and communications links. It takes teams of specialists from almost every field of study. The picture of this trend, at least for someone with a historical mind, forms an arching curve that throws back some of its layers to retrofit older, simpler tools of recent past (automobiles, airplanes, telephones, typewriters, and the like), while thrusting up and forward to create new orders of complexity that, like our computers, are no longer called tools, but systems. This kind of growth is quite unprecedented. It is testimony to the awesome power that digital technologies release, and it makes this experience very different from anything that has come before in history. Quite literally we have machines and software that participate in a very direct way in advancing their own evolution while accelerating evolution in other technologies, and pushing it all forward at an exponential rate. This fact greatly affects how people perceive and interact with the products that come into their hands, if only because with increased complexity comes increased pressure to learn and adapt. And this pressure is almost continuous.

Moreover, with this increased complexity comes increased opportunities for things to go wrong. And things do go wrong with technologies, all technologies. Machines break down. Sometimes they simply don't perform as advertised. The more complex and interdependent our technologies become, the more that can go wrong; I cannot help but think of all the computers, modems, service providers, telephone companies, telephone lines, cable networks, backbones, satellites, and all those gigabushels of switches, and how fragile it all seems when Nature steps in to take out a power quadrant in the Pacific Northwest, or when the system simply becomes over-burdened with activity.

A recent very public example of technology with egg on its face was the Microsoft misfire at the Chicago Comdex gathering, where a demonstration of its new operating system crashed the computer. This shocked no one, of course. Most of us found it rather amusing. After all, it was not the first time, and none of us believe it will be the last. Nor was this a catastrophe by any means, except perhaps for the Microsoft public relations office. But it does point to the complexities that make these kinds of mishaps inevitable. In our rush to put complex technologies on the market we fudge the details, cutting and pasting fragile structures to give the public more bells and whistles. The ethics of business, on the whole, are… well, I think the word is *flexible*. The consumer must at all costs be persuaded to buy the latest improved version of something, anything, everything. Third-quarter profits must exceed second-quarter profits, or else the stockholders might get nervous and consumers might have time to think that maybe, just maybe, they don't really need to buy the latest gizmo.

The push for more complexity, most of it in the form of software bloat and creeping featurism, is driven by market perceptions, not technical necessity. More bells and whistles don't make computers or people more efficient, and most often they make both less efficient. There are good studies that show that productivity has in fact fallen since the introduction of these machines. We produce more paper than ever before, but get less real work done. Estimates vary, but some suggest that the loss of productivity may be costing businesses anywhere from three to five thousand dollars annually per machine. Even for civilians like me, people who work mostly at home and on their own schedule, this complexity gets in the way of work all too often. When we have work to do, work that requires our full concentration, we don't want "neat" and "cool"; we want coherence, quiet efficiency, and simplicity. We don't want to have to think about the tools we are using. I don't spend much time thinking about my pencil until it needs sharpening. I expect it to make proper marks on my paper and erase the mistakes—nothing more. If my pencil is going to start chirping and sending up error messages I'm going to throw the thing away and find something that knows how to be a properly respectful tool. As it happens, I am someone who likes to think about computers on occasion, but I prefer to do it on my own schedule, not the computer's.

The Shape of Technology

I'M GOING TO SHIFT GEARS NOW to talk a bit about the shape of technology. I will be mentioning graphic artists and industrial designers; for our purposes you should understand that the graphic artist is someone who works primarily with surfaces, while the industrial designer is someone who works chiefly with the shapes and surfaces of objects. I want to suggest that both graphic artists and industrial designers, working in collaboration with engineers, can make these technologies less burdensome and easier to use, especially when it comes to designing the points of human interaction, the touch points. Rather than propose detailed schemes, my aim is to put forward some ideas to encourage the kind of broad thinking that is needed to produce not only better technical structures, but better human technology interfaces.

I believe strongly that both utility and beauty are essential in the making of things. Whether we are building bridges and cathedrals or designing computers and software, beauty is a necessary component, not just on the exteriors of these things, but also in their underlying structures. Or, to put it in the vernacular: beauty is more than skin deep. I've never seen a well-made bridge or cathedral that wasn't also quite beautiful, nor have I experienced a truly useful software application that was not also elegant in its feel and appearance. Structural engineers and industrial designers have collaborated often and to good effect throughout history, proving that engineers are more than mere technicians and that industrial designers are more than decorators of empty shells.

Mathematician Jacob Bronowski, in a very interesting little book published in 1978 by MIT Press and entitled *The Visionary Eye,* wrote about things like art and technology and how things are made. Central to his theme is the idea that "We express logical relations as structure; and we express structure as shape." He goes on to explain how it is in that sense that all technology has a shape, a final form. And this final form, he said, is constrained at all times by a triangle of forces, which he details as follows:

1) the tools and processes necessary to make something;
2) the materials and technical structures required to make it;
3) and, the use to which it is to be put.

I would add that the quality of the thing made is also constrained by another triangle of forces, namely:

1) the training and experience of those making it;
2) the intelligence and imagination of those making it;
3) and, the depth of resources available to pay for its development and manufacture.

The constraints in both sets apply to all who contribute to the making of something, be they engineers, graphic artists, or industrial designers.

Poetry, Beauty, and Elegance

Within these sets of constraints mathematicians, engineers, graphic artists, and industrial designers alike strive to identify ideal types, to find what we like to call "elegant solutions." Elegance is highly prized in all disciplines. Philosopher and historian Etienne Gilson said:

"The unity of the human mind is such that, just as there is intellectual knowledge in all that man does, or makes, there seldom is a complete absence of art in what a man knows."

What defines elegance in each case may be quite different, but at the root is our very human need for things that satisfy both the mind and the eye. In mathematics these might be beautiful equations that have profound implications. In engineering these might be powerful structures that achieve maximum efficiency with very little cost to the total system. In industrial art these may be beautiful and coherent surfaces or shapes that both invite and enhance the experience of use. In science and in art this elegance is always transformative, in the sense that it enriches the object at hand while widening the possibilities for what will follow. When poet William Blake said "excess is the path to the Palace of Wisdom," he was referring to human behavior, not the shape of things. His poems, some of the most powerful creations ever put to paper, are models of economy. More than a century later, their power has not diminished. They are timeless. They are elegant.

Poetry, beauty, and elegance: Can such things really have direct and vital connections to the making of things like computers and software? Well, I think so. We are moving into a phase of this technological revolution where it now becomes critical to think in these terms. Engineers who design buildings and bridges have long understood this, and it's only because of the youth of the field of software engineering that it has yet to discover its own aesthetic footing. The very complexity of these rapidly evolving and spreading technologies makes it absolutely essential to recognize that what we make must be both beautiful and useful together. Many who work in the computer industry seem to sense that something is missing, but they haven't yet discovered what it is. I think if we can at least agree that these technologies are made for people, real people, individuals with distinct personalities and blood coursing through their veins, and not cartoonish statistical people, then we will have moved a long way toward coming to a better understanding of what is involved in making things people not only don't have to think about, but things that fit their lives in a very accommodating way.

The obstacles to making these new tools both useful and accommodating are really not so imposing as many seem to think. Laboratory studies of human behavior may be good for the *curriculum vitae* of those who conduct them, but, so far, they haven't yielded much that enlarges our understanding of what it is to be a human being in the flesh and bone of reality. It's really just a matter of widening our perspectives, to open ourselves to the human experience in its full measure. Those who make these technologies are human beings, just as those persons who will use them are human to the core. If we can learn to separate ourselves from our specialized knowledge long enough to appreciate the common thread of our humanity, then I think we might actually learn something.

For too long the design of the external surfaces of these technologies has been approached as an afterthought, something to be pasted on after the hard work of designing the technical structure is finished. The Macintosh computer and operating system is the one striking exception: it represents an effort from the outset to develop the machine architecture, system and application software, and graphical interface as a coherent whole. Windows, on the other hand, is a paste job overlaid on DOS, itself an adaptation for hardware technologies already developed by IBM and Intel. I only hope that future development of these and other systems will follow the example set by Apple in this regard. Indeed, I have to hope that Apple can continue to follow its own good example.

How the user experiences a tool can have a direct bearing on its ultimate utility. We know this from very long experience with other tools, whether simple or complex. You can drive a nail into a board with brute force using no more than a rock of sufficient size and hardness. But it's not much fun, and you can do some real damage to your knuckles if you aren't careful. If, on the other hand, the rock is shaped for the hand at one end and for pounding at the other, it works better. We can find among the technologies of the stone age, ranging as far back as 200,000 years ago with Homo Sapiens and almost two million years ago with Homo Habilis, evidence of some very good thinking. In fact, we find that in some places they developed prototype models that were meant to instruct others in both the techniques required for making the tool as well as the shape that should result. However rudimentary these tools might have been, they demonstrate that keen sensibilities were at work to solve some very difficult problems. The results in many instances were quite beautiful.

I will say it again: elegance is transformative. One of the things that is common to most elegant design solutions is the sense of familiarity that one experiences, even when they are entirely new things. They have a logic that is "natural," by which I mean we can recognize it immediately and say "Aha! I understand. That makes perfect sense." I saw a fine example of this kind of thing in an article on eighteenth-century Japanese temple art. These were designs created by mathematicians. They engraved them on wooden tablets and hung them in the rafters of temples and shrines. They are in fact mathematical puzzles using colored geometric shapes. The instant I saw these things I recognized what they were, though, for a fact, I had never seen them before. They are quite striking, and also familiar. I could deduce their purpose and appreciate their beauty without knowing anything of their history.

This is what we are doing when we create so-called "intuitive" interfaces. We are creating an environment where this natural logic allows people to recognize what must be done. This natural logic must exist simultaneously in the underlying structures and on the surfaces. It cannot be in one place and not the other.

Standardization of Interfaces

A different but equally important kind of familiarity is produced when we are able to standardize functions and paths of human interaction. Around us are some very good examples which have worked well with some rather complex technologies that appeared over the past century and a half. Topping the list are things like automobiles, cameras, and telephones.

The user interface in automobiles has remained essentially unchanged since about 1910, when automobiles first went into mass production. Steam cars and other varieties of automobiles or horseless carriages had been around for about thirty years prior, each with its own sort of interface. They tried a variety of steering mechanisms, throttles, valves, pedals, levers, and gears, but once these machines went into mass production and began to be distributed widely in the mass market, standardization of the user interface became critical. And, of course, a person today can drive a 1949 Chevy as easily as he or she can drive a 1998 Cadillac. The essential interface is the same for all cars, whether we are in Hong Kong or Detroit. The variations that come and go are mostly in the non-critical details.

The 1888 Kodak box camera introduced a simple, straightforward interface that allowed anyone, whether they knew anything about photography or not, to make good photographs. Before 1888, anyone wishing to make photographs had to learn some rather complicated procedures, build a darkroom, learn something about photo-chemistry, and be willing to get a little messy. The slogan for the 1888 Kodak read: "You Push the Button, We Do the Rest." There was even a popular song by that title extolling the virtues of the camera. The claims were essentially true; you bought the camera already loaded with film. (This was also the introduction of another innovation—roll film.) After you made about a hundred exposures, you would ship the camera to Kodak, where the film would be developed, prints made, and the product returned in the form of an album. They would also return your camera loaded with a new roll of film. This is the very model for today's instant and disposable cameras. While the underlying technology has improved, becoming more complex, the exterior interface remains unchanged. It's bone simple. You push the button, they do the rest. It has worked very well that way for more than a hundred years.

Telephones: we still refer to it as "dialing," even though that's no longer what we do. I'm not sure when dial telephones were first introduced, but I know that it was in the early part of this century. There was nothing tough to remember, just the numbers one through nine and a zero; you lifted the receiver, listened for a tone, dialed, connected, and talked. This simple interface persisted until the arrival of touch-tone telephones about fifteen or twenty years ago. The addition of pound signs and star symbols didn't complicate things that much. Where things get complicated with telephones today is with the programmable models. For a lot of people it's like trying to program a VCR or a fax machine. There are too many choices hidden in rather arcane click-through menus on unreadable miniature LCD displays. And you really don't use them often enough to remember the procedures. Familiarity comes with routine, almost daily use. Things that we don't do every day tend to be forgotten. That's a small point, but one that needs to be remembered as we try to develop better ways of doing these things.

This business of standardizing interfaces and of setting standards and protocols has been around for awhile. We have ANSI (American National Standards Institute), which has a variety of committees, sub-committees, and panels that meet regularly to set technical standards in a host of fields, including many fields related to the electronics that go into most computers. There's the IISP (Information Infrastructure Standards Panel), which according to its publications has made human technology interface a priority, though I'm not sure how serious they are about getting the job done. They crank out reports of their discussions and make some rather high-sounding statements; but, so far as I'm able to determine, that's about as far as it goes. Tim Berners-Lee at MIT heads W3C (World Wide Web Consortium), which sets and maintains standards and protocols for the operation of the Web. They do much better with human factors than most groups, and Berners-Lee himself deserves much of the credit. He has both vision and the ability to lead, qualities not widely distributed among those who serve on committees and panels.

Graphical User Interface

There is a lot of talk now about the Graphical User Interface (GUI) being twelve years old, that it's time to move on. What I don't hear in any of this is the criticism that it doesn't work. The only criticism seems to be that it's twelve years old. What this suggests to me is that a lot of people, mostly software engineers, have a lot of time on their hands, and they don't mind wasting other people's time. So what if it's twelve years old? The only relevant questions are: Does it work? Are people becoming comfortable enough with it to reduce the error rate in their operation of these technologies? And is there something we can do to improve existing graphical interfaces to help them recover faster when something does go wrong?

Those who ask us to move on from GUI to new things are also the people who suggest "cool" and "neat" alternatives that have no proven record, and, so far as I can tell, offer little to improve the ease of use of these technologies or increase productivity in the workplace. The chief cause of productivity loss is the amount of "futzing" required to figure out how something is supposed to work; other causes include recovering lost data, trying to fix bugs, and waiting for service technicians. I've heard discussions about two-handed approaches with joy sticks or rearranging the keys on keyboards. That's fine, but do we really think people need to learn to juggle while grappling with what is already in front of them in the way of new and unfamiliar things?

I'm convinced that graphical interfaces are a permanent feature of computers, including the communications and networking components, and especially with respect to the Web. Web pages are very much like computer applications or operating systems: they don't just sit there, they do something. In some respects we could call them mini-operating systems. And, as it happens, these little systems lend themselves very nicely to graphical solutions. When you are mixing large quantities of text, graphics, and data, you need careful and imaginative design. Even more sensitive are the navigational devices and schemes required to make them work.

Graphical interfaces are not easy to design, not good ones. You don't have to look very far to find the proof. About two-thirds of what we find in the marketplace is poorly done. Yet good graphical interfaces can overcome many obstacles that, as David Norman put it, are more sociological and organizational in nature than technical. Some of the best thinking about interface design has come out of our nation's space programs. A very interesting graphical strategy was employed by the scientists who dream of communicating with distant alien civilizations. Back in 1977 they made plaques attached to the Pioneer 10 and 11 spacecraft. The plaques contain some fairly simple graphical representations of who we are and how to find us. Scientists believe these symbols can be easily recognized and interpreted by another intelligent species. They included this plaque on the Voyager spacecraft as well, adding a CD that contains the sights and sounds of Earth; the instructions for using it are engraved on a plate with another set of rather cleverly conceived drawings.

The problem of communicating with distant alien civilizations may end up being a piece of cake compared to the challenges we face just communicating effectively with one another here on Earth, or even here in Southern California. More than 120 languages are spoken in Los Angeles County alone, some of them fairly obscure. We know the kinds of problems government agencies, schools, and businesses have in overcoming language and cultural barriers. We also know the difficulties of finding uniform approaches to the use of such things as library computers, automated parking systems, bank ATM machines, and so on. We know from experience and from research over the past decade that reading is a thought-intensive activity and therefore slower than, say, pattern recognition. But add to that the wide differences in language, culture, and educational background among users, and the problem gets infinitely more complex. Graphical interfaces can, when done properly, transcend language and linguistic differences; the language of shape, line, color, and pattern is a language common to all. We need only perfect our approaches so that they will in fact work equally well for all.

The HCI (Human Computer Interface) group has at least recognized that good graphical interface design requires an interdisciplinary approach involving engineers, ergonomics experts, psychologists, and graphic artists. And, if we're going to insist on publishing manuals to go with these technologies, I think we'd better add professional writers to the list, and we'd better get multilingual while we're at it. Manuals are some of the most poorly written pieces of literature on the planet, and as a result they do little to help us through our problems with these technologies. Where I find fault with the HCI program is in their suggestion that all this knowledge and all these skills would ideally be contained in one person, a "GUI specialist." The word "specialist" itself runs counter to the notion of an interdisciplinary approach. It would be much more sensible to recognize that no one person can do all this, and that it is probably better in the long run to help our many specialists to learn to work together, each bringing the maximum of their knowledge and skill to the task. In working together, each would gain sufficient knowledge of the work of the other to make that collaboration truly meaningful.

An engineer must have a sense of the shape his or her structures will take. An industrial designer must have a sense of the underlying technical structures that will constrain his or her shapes and surfaces. The ergonomics expert must have a sense of both the shape of the tool and its use, as well as the structure of the human being who will use it. The psychologist must know as much about the technology as he or she does about the emotional states and cognitive responses of the person using it. We could go on with lists of workers in many fields who contribute to making these technologies, seeing in each case how their specialized knowledge is not enough, how it is necessary for each to know something about the work of the other so that effective collaboration can lead to more perfect results—so that, in the end, the power of the whole can in fact become greater than the sum of its parts. A poem can be both beautiful and powerful. I believe it is possible to achieve this kind of power in our technologies. We need only widen our vision and open our minds to the possibilities.

Epilogue

It's high time that we all come to some better understanding of what it is that each of us has to offer with respect to this work. After all, as soap peddlers keep insisting, "the future is now." Bronowski warns that "If the artist refuses to learn … what the scientist is discovering about the materials in which he must work, then of course he will find these limitations a burden. And, equally, if the scientist is too bigoted to feel himself into the sensibilities and living values of the artist, he will propose only dead structures." With that in mind, all of us would do well to remember that the path we have followed for at least two million years is a common path, shared by all human beings in all places and in all circumstances. And that our success as a species is built upon our collective enterprise and intelligence, *not* our private vanities.