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Abstract

In his book *Designing Engineers*, engineer Louis Bucciarelli answers the question “Do you know how your telephone works?” with the rhetorical rebuttal, “Does anyone know how their telephone works?” At first pass, we might be inclined to assume that engineers, scientists, or computer scientists are by default technologically literate—if anyone knows how the telephone works, surely it is them. But the intent of Bucciarelli’s question is to point to a deeper ambiguity about what it means to “know” how something works, even in the case of a technical expert. Essentially what he is asking is “Is anyone really technologically literate?”

This is the question I will explore philosophically in this paper, with particular focus on the technological literacy of technological professionals such as engineers. I will begin by examining the definitions of, and criteria for, technological literacy provided by the NAE report *Technically Speaking*. I will examine the extent to which those criteria might be satisfied, both for lay people as well as technological professionals. The *Technically Speaking* report describes some general obstacles to achieving technological literacy. I will discuss these challenges and offer some additional ones, including some to which technological professionals contribute, and others which primarily affect technological professionals. I will close by offering some general observations from an engineer’s perspective on the definition and goals of technological literacy.

Engineers’ Contributions to Technological Literacy

If there is a need for the increased technological literacy of people in our society, then it would seem patently obvious that engineers could and should play a vital role in helping to fulfill that need. Thus, the ITEA’s standards document lists the engineering profession among the groups it calls to action.¹ Likewise, the National Academies report on technological literacy states, “The technical community—especially engineers and scientists in industry—is largely responsible for the amount and quality of communication and outreach to the public on technological issues.”² One of the editors of that report, Pearson, has elsewhere discussed the need for the engineering profession to become more engaged with the technological literacy effort.³ For a more specific example, engineers Ollis and Krupczak have proposed that at the college level engineering design faculty could be the primary providers of general technological literacy courses.⁴

But the engineering profession has not been entirely absent when it comes to popularizing an understanding of engineering and technology. As Pearson points out, the engineering profession has traditionally seen itself as misunderstood or undervalued, which has spurred engineering professional organizations to undertake a variety of efforts throughout the years to publicize engineering and technology.³ Of course, the ultimate success of such efforts is debatable since periodic polls seem to consistently reveal a lack of understanding of those topics by the public. Nonetheless, the profession has devoted resources to the cause. In fact, engineers have a more narrowly self-interested motivation to continue such efforts than just the hope of achieving any general technological literacy. Filling the educational pipeline with young people prepared for, and interested in, careers in engineering is a crucial objective for the profession and one that

depends on sufficient numbers of young people—and their parents—understanding the profession and what it does.

I personally support wholeheartedly the movement to increase the technological literacy of our citizenry and I applaud those who have made efforts to advance that cause. In fact, I have developed and directed engineering and computer science summer camp programs for middle school students, I frequently make presentations at schools and career fairs, and I have taught courses in the history of science and technology to college students from non-technical majors. I note these things about myself only because in what follows I may cast the impression of pessimism or negativity about the goal of technological literacy. But my purpose is simply to discuss some systemic problems and contradictions that I perceive with respect to technological literacy—in particular as it relates to engineers—in order that those problems may be confronted.

Engineers' Uncertainty About Their Own Technological Literacy

In his book *Designing Engineers*, engineer Louis Bucciarelli recounts listening to a conference speaker who presented statistics on the low rate of technological literacy among our citizenry, giving as one example the small percentage of people who know how a telephone works.⁵ Bucciarelli admits to suffering a bout of anxiety because he wasn't sure that even he could explain how a telephone works. But the more he thought about it, the more it dawned on him that his real conundrum was understanding the question "How does a telephone work?" Does it mean the understanding physics of the device itself, or knowing how to use the device (dialing, etc.), or knowing the physics of how the telephone network works, or understanding the algorithms for routing calls, or understanding the politics and economics of the telecommunications industry, or knowing what a telephone repair person does after climbing a pole? I might add, thirteen years after Bucciarelli's book was published, the list could now include understanding the physics of wireless technology, or how to choose a telephone that best suits you, or how to choose the best wireless company and wireless plan for your needs, or even how to download ringtones onto your phone.

In the end Bucciarelli determines that he has a pretty good understanding of how the telephone works in some of these senses, a more limited understanding in others, but is relatively clueless as to the rest. So who has the complete understanding? "I can claim fairly confidently," he concludes, "that there is no single individual alone who knows how all the ingredients that constitute a telephone system work together to keep each of our phones functioning." That is, there is no one who is technologically literate about telephones in any absolute and comprehensive sense. Yet we all adapt them to our own needs and purposes.

Another example of an engineer expressing ambivalence about technological literacy comes from Raghu Garud, who writes, "It is a source of consternation to my wife that, despite my engineering education, I am all thumbs when it comes to fixing anything."⁶ Like Bucciarelli, Garud goes on to discuss the different ways in which we can "know" something about technology, and how those ways of knowing do not necessarily coexist in a given individual. His comments resonated with me given that I am someone who can explain in much theoretical detail how most of the systems of an automobile work, yet I find myself placing blind faith in the competence and veracity of the mechanic when anything goes wrong with my own.

In a related vein, sociologist Kathryn Henderson has found through interviews with design engineers that they often are intimidated by technologies that are new and unfamiliar, which is juxtaposed with their being comfortable or even blasé about those technologies with which they have expertise. “After all,” writes Henderson, “any given piece of high technology is not something every engineer understands. If it is outside his or her specialty area it is mystified.”⁷

I recently conducted an informal survey of students in my junior year engineering design course, asking, among other questions, “How would you describe your level of knowledge about technology?” In keeping with the foregoing examples of equivocation on the part of engineers with respect to their own technological literacy, my students’ responses had an overall dual character. While there were a handful of students who felt very confident in their knowledge (e.g., “I have a top-level knowledge of modern technology...”), the predominant type of response was more along the lines of, “I’d say that in the grand picture, I know a lot more than most in the world. However, judging by the amount of technology available today in the USA alone I would have to say that I know only a small fraction of technology and that there is much more to be learned.” That is, the responses tended to both acknowledge the advantages conferred by studying engineering when it comes to understanding technology, while at the same time conveying a feeling of being overwhelmed by the seemingly limitless scope of technological knowledge. The latter is evident in comments such as, “the more you know, the more you realize that you don’t know,” and, “my level of knowledge about technology is just the tip of the iceberg,” and, “I work really hard to be as advanced as possible, but enough is never enough with the advances these days.”

Despite only knowing the tip of the iceberg, engineers are highly successful at getting things done. Specialization and division of labor are key. In addition, engineers utilize a variety of techniques to reduce complexity and minimize what needs to be understood in order to solve a problem. By making simplifying assumptions, drawing control volumes, ignoring as many peripheral variables as possible, idealizing constraints, and approximating values, engineers aggressively strip problems to bare essentials. Auyang lists fundamental heuristics that recur in the design strategies of engineering industries, from aerospace to electronics.⁸ They include *simplify, simplify, simplify* and “choose elements with low external complexity and high internal complexity, so that the elements are as independent as possible.” The latter heuristic, which also presages a discussion topic in the next section, is crucial to the systems perspective that pervades engineering thinking, a perspective that is generally prominent in definitions of what it means to technologically literate.

But that systems perspective is a double edged sword when it comes to technological literacy. On the one hand it allows an engineer to deal with the *big picture*, integrating disparate parts into a functional whole. On the other hand, it can absolve one of having to understand the workings of other parts of the system. By choosing elements with “low external complexity and high internal complexity,” we mean we desire to choose elements which we can treat as black boxes which perform functions we want given some straightforward inputs, but we do not need to know how or why the inputs result in the outputs—that is somebody else’s problem. In the other direction, the system we are working on, into which we incorporate black box elements, might itself be an element of a higher level system. We can in turn distance ourselves from any understanding or

interest in that higher level system by limiting our scope to the knowing what inputs and outputs are required at the interface.

For the most part, the limitations on the technological literacy of engineers described above are with respect to an instrumental understanding of technology—i.e., just because you understand the technical details of one technology does not mean you understand the details of all technologies, or even very many. But there is another limitation on the technological literacy of engineers, one that is noted in the National Academies report, which states, “Even engineers, who have traditionally been considered experts in technology, may not have the training or experience necessary to think about the social, political, and ethical implications of their work and so may not be technologically literate.”² As any engineering educator can attest, many of our students express that one of the reasons they gravitate to a technical field is that they are more interested in what they perceive to be the “concrete and objective” world of technoscience, and would like to minimize their contact with the fuzzier world of social, political, and economic concerns. Heretofore, engineering education has largely obliged these students by concentrating the curriculum on technical analysis. I have hope, though, that the winds have changed. With ABET’s new requirements for inculcating an appreciation of ethics, societal impact, global issues, and current events, coupled with the current push toward preparing students for a “flat earth”, I believe we will see increasing progress in producing engineering graduates with greater awareness of the technology’s relationship to society.

Engineers’ Contributions to Technological *Illiteracy*

The National Academies report, *Technically Speaking*, notes several factors that contribute to technological *illiteracy*.² These factors include the complexity of modern technology, the specialization of societal roles, the urbanization of the population, the automation of the workplace, and a shift to a service economy. An additional factor is described as follows: “Most modern technologies are designed so users do not have to know how they work in order to operate them.” The key word here is *designed*. If technologies tend to be black boxes which the average person learns to utilize without any real understanding of how they work, and if such a state of affairs is a causal factor in fostering technological illiteracy, then engineers are implicated as architects of that technological illiteracy.

Albert Borgmann coined the term *device paradigm* to describe much of modern technology. The device paradigm suggests that modern technologies are designed specifically to enhance the ends of the technology (such as ease of communication in the case of the telephone) while removing the means from view as much as possible. “The concealment of the machinery and the disburdening character of the device go hand in hand. If the machinery were forcefully present, it would eo ipso make claims on our faculties. If claims are felt to be onerous and are therefore removed, then so is the machinery. A commodity is truly available when it can be enjoyed as a mere end, unencumbered by means.”⁹ Because of the powerful marketability of “ends unencumbered by means,” engineers have been proficient and prodigious in making the concealment of means a reality, and they do so as an explicit design goal.

We are all familiar with the term *user-friendly*, which we apply to a technological product that is easy to use and to understand. But when we say *easy to understand*, we do not mean it is easy to

understand the underlying technological principles. Rather we mean it is easy to understand how to get it to do what we want it to do, and this often is purposely divorced from any knowledge of those underlying technological principles. In fact, the design trend is toward technologies that will do what we want them to do with less and less explicit input or manipulation on the our part. Take for example the ideas of Donald Norman, a proponent of human-centered computer technology. He writes,

“Today's technology imposes itself on us, making demands on our time and diminishing our control over our lives. Of all the technologies, perhaps the most disruptive for individuals is the personal computer. The computer is really an infrastructure, even though today we treat it as the end object. Infrastructures should be invisible: and that is exactly what this book recommends: A user-centered, human-centered humane technology where today's personal computer has disappeared into invisibility.”¹⁰

Norman echoes Borgmann in pointing out that technology imposes a cognitive burden on us, one which were are generally happy to relieve if possible via user-friendly, invisible technologies. But whereas Borgmann—a philosopher—views that trend as concerning, Norman—an engineer—celebrates it as a worthy objective. The more invisible the technology, the less the user has to know about it, the more successful the designer. This is a common design principle in the realm of ubiquitous, embedded computing technology. “One of the driving forces behind the emerging interest in highly interactive environments is to make computers not only genuinely user-friendly but also essentially invisible to the user.”¹¹

This is emphasized by a recent article in the *EETimes*, an industry newspaper for electronics engineers, which states that technology “wants--and needs--to become transparent, if not completely invisible to today's techless, clueless consumer.” The article refers to the design of such transparent technology as *invisible facilitation*, which it says “is rapidly emerging as the design rule of the day.”¹² The article implies that the “techless, clueless consumer”—i.e., technologically illiterate consumer—is a problem to be solved. But the solution strategy in this case is not to educate consumers about technology, but rather to increasingly design technology to cater to consumers’ low level of technological knowledge.

In a research paper on why engineers sometime design poor user interfaces for technologies, the authors attribute such failures to the fact that engineers are biased toward designing the interface to reflect the underlying mechanism of the technology, an interface style which the engineer, who understands the underlying mechanism, finds intuitive but the user does not. Rather, the authors conclude, a *black box* model for the user interface is more effective for the user—that is, an interface which is modeled upon the tasks the user has to accomplish, with the underlying mechanism of the technology that effects those tasks obscured from view.¹³ Historian of technology Edward Tenner makes a similar point in his book, *Why Things Bite Back*. “A sequence of typewriters recently exhibited at New York’s Cooper Hewitt Museum,” writes Tenner, “made it clear how industrial designers (and their customers) have been increasingly determined over the years to conceal these mechanisms...As the new models were finished in almost every color but black, typewriters were already on their way to being black boxes in the technological sense: mechanisms opaque to the user.”¹⁴ In addition to *user-friendly* and *black box*, other familiar terms which convey the notion of usability without understanding—and

which are pursued as good things—include *plug-and-play*, *turnkey system*, *human-centered design*, or *user-centered design*.

The black box nature of technologies is further reinforced by engineers' success at improving the reliability of technologies. For example, many consumer products are now likely to become obsolete and be replaced long before they ever malfunction, which gives users little incentive to ever open up the black box and look inside. Tinkering is further discouraged by warning labels such as the familiar "No user serviceable parts inside," which is tantamount to saying, "Don't bother opening the case because you won't understand what you're looking at anyway." And even for many products that do break, the availability of low cost materials and efficient means of mass production—both engineering achievements—make disposability a more cost effective solution than repair, obviating the need for the knowledge required for the repair.

In addition to increasing reliability, engineers have also been successful at increasing safety for many technologies, at least in the sense of acute or immediate safety. And as with reliability, safety can have a propensity to distance the user from the technology. Studies in risk perception show that as risk goes down, complacency goes up. People begin to take technologies for granted and are less likely to make critical assessments. Of course the Faustian tradeoff for the elimination of many acute risks through improved technologies is their replacement with long-term or chronic risks—e.g., accumulation of pollutants, depletion of resources, etc. But people tend to perceive displaced risks (in space or time) as being of less importance. In short, by being so successful in making the technological world safer and more reliable, at least in an immediate sense, engineers have conditioned people to be less discerning of technology. And this isn't just an unintended consequence; rather it is a selling point. Consider the following passage about a hypothetical sleepy driver, taken from an article discussing advances in automobile safety: "Startled awake, the driver seizes control, overreacts and risks losing total control. Again, no worry. The vehicle is fitted with electronic stability control."¹⁵ The striking terminology is *no worry*—the technology allows you to put risk out of your mind.

The great irony is that even as engineers might recognize the need to promote technological literacy, and make various efforts toward that end, in the context of their actual work they are caught in a resonant feedback loop with consumers with respect to technological *illiteracy*. The more user-friendly they make their designs, the less consumers need to know about the underlying technology, and the less users know about the underlying technology, the more user-friendly they demand their technologies to be. Returning to the discussion in the previous section about systems thinking and its reliance on independent elements with low external complexity and high internal complexity, we can see that the lifestyle of a modern technological society is a paragon of systems engineering. The technological elements we integrate into the 'system' of our daily lives have those very properties—low external complexity and high internal complexity—that make for efficient system design and operation.

This effect is perhaps compounded by another that Henderson suggests, which is that it serves the interests of both engineers and their companies to retain a black box character for their technologies.⁷ Henderson points out that a defining characteristic of any profession's culture is the knowledge of things which people outside the profession do not know, and thus there is

pressure to keep that knowledge boundary relatively intact. Engineers, as much as any other professional group, want to protect their prestige and expertise. They would like for the public to understand what they do—but only up to a point. As for companies, the motive is unsurprisingly related to the need to protect their proprietary information and hence their economic interests. The drive to shield the internal workings of a technology from public view is highlighted by a recently proposed legislation called the Motor Vehicle Owner's Right to Repair Act. Proponents of the legislation claim that neither individual owners nor independent auto mechanics can effect certain types of repairs on many new vehicles because automobile manufacturers will not release the access codes and tools needed to diagnose and complete the repairs.¹⁶ Thus, owners are forced to take their cars to dealerships for repairs. The opacity of the technology, not only to the user but also to skilled technicians in this case, is a purposefully designed attribute.

Concluding Remarks

I'm not sure what the solution is, if there is a solution, to the paradoxical relationship between engineering and technological literacy. On the one hand, because of their expertise engineers are prime candidates for communicating an understanding of many facets of technology to the wider public, and the profession appears to have the desire and a compelling interest to do so. On the other hand, through their work engineers seem to be making an understanding of technology more inaccessible to the wider public as rapidly and intentionally as possible. Perhaps this conundrum will act as a daunting barrier to any hope of achieving a more comprehensive technological literacy. Or perhaps we may eventually find a new technological paradigm that would bring the two objectives—a wider understanding of technology, and the design of useful technologies—into greater harmony.

A recent survey of the people in the United States found that people are split when it comes to providing more math and science education for our citizens. Roughly half the respondents do not think we need more. And roughly half also suggested that the reason students avoid those subjects is because they are too hard or would hurt students' grade point averages.¹⁷ A commonly voiced concern (e.g., in the National Academies report²) is that the American public's lackadaisical attitude toward technological education threatens our economic competitiveness and our standing as the world leader in technology. Many developing countries appear to be having more success than we are currently when it comes to enticing students into pursuing technical careers.

I find an interesting parallel between this fact and some of the research into organizational complexity.¹⁸ In organizations with low environmental complexity (i.e., limited and straightforward demands from the environment external to the organization) there is little inducement for members of the organization to learn new things because the status quo is sufficient. In organizations with high environmental complexity (i.e., an external environment which places heavy, constant, and varying demands on the organization) members of the organization are swamped with activity and have little time for learning. In such cases, the value of tools and techniques that can improve productivity without requiring much cognitive overhead is high. It is in organizations with moderate levels of environmental complexity that the propensity for members to learn new things is maximized, because there is both the incentive to improve and the time to invest. I don't want to make too much of any ad hoc extrapolation of

organizational dynamics into global socio-economics, but I think it makes for interesting food for thought. We might say that a lifestyle in a highly developed country like the U.S. has high environmental complexity with respect to technology, whereas a lifestyle in many underdeveloped countries has low environmental complexity. In both these cases, the drive to become more technologically literate is probably less intense than that in a developing country for which the environmental complexity is moderate. We are, as it were, victims of our own prior success. Our only consolation may be that the developing countries are destined to suffer the same fate as they close the gap with us.

As a final remark, as much as I am for promoting technological literacy, I can't help returning to Bucciarelli's uncertainty as to what it means to be technologically literate, or if such a thing is even achievable. I am particularly overwhelmed by the ITEA standards, which call for students to understand medical technology, agricultural technology, power technology, information technology, transportation technology, manufacturing, construction, engineering design principles, and the engineering design process, as well as be able to do design, to use and maintain technologies, and to assess technological impacts. Further, students must understand technological principles, the history of technology, characteristics of technology, the politics of technology, the economics of technology, the impact of technology on the environment, the impact of technology on society, and the evolution of technology within society. Even as a PhD engineer who has a particular side interest in technology and society studies, I feel unworthy of calling myself technologically literate when I stand before that list! And if I can impart even a fraction of that to my engineering students I feel successful. I recall reading a biology article once which claimed that if everything on the earth disappeared—including the earth itself—except for nematode worms, the outline of the earth and everything on it would still be clearly visible because nematodes are ubiquitous in everything. In a similar way, I get the feeling that if humanity's collective knowledge evaporated—except for any knowledge related to technological literacy as defined by the above list—our collective knowledge would remain largely intact!

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