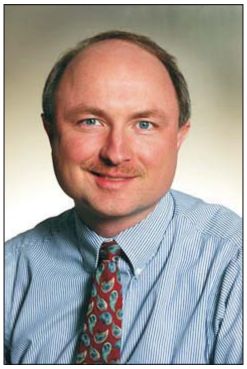

Steven H. VanderLeest

Engineering Is Not Science

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Engineering is not merely the application of science. While science is certainly an important factor in the engineering design of technology, subsuming engineering and technology under the umbrella of science obscures important differences. Following a structure suggested by Paul Forman, the two are distinguished, exploring the primacy of science in the modern era and the primacy of technology (and engineering) in the postmodern era. However, placing either practice above the other does not do justice to both: a symbiotic or interplay model is more appropriate. Recognizing the distinctive yet interdependent activities of science and engineering produces better insights. This interplay also suggests some benefits related to the exercise of Christian faith: providing multiple modes of worship, avoiding idolizing "-isms," and understanding our roles as stewards.

The act of categorizing illuminates certain characteristics but obscures others. Many academic disciplines can be divided into "lumpers," combining similar things into larger categories, and "splitters," dividing dissimilar things into smaller subsets. Categorization is a helpful mental model, but either strategy carried to extreme loses its value. Lumping everything in a unified category is too bland to make useful inferences; splitting everything into singular categories is too fragmented to provide helpful insights.

More than a simple cognitive aid, cataloging represents political power. Insensitive men have lumped both genders under the label "mankind." Disrespectful whites split off persons of color into a separate category of blacks (or more derogatory terms) in order to deny rights and even to deny personhood. Categories and labels become terms of respect and justice—or the lack thereof. This article examines the importance of the categories and the names of science and engineering.

This article's structure follows Paul Forman's division of history in the year 1980. He tips the scales to favor science prior to, and technology after, that date.

> Liberation of our conception of technology from the functional dependence and cultural inferiority implied by "applied science" was a principal constitutive program of the discipline of the history of technology … When the historians of technology first began to revolt against "the linear model" and its view of science as originative source, as unmoved mover, of technological progress, they were setting themselves against prejudices deeply entrenched in modern culture … In the epochal global transformation from modernity to post-modernity that has been taking place in recent decades, technology has acquired, beginning about 1980, the cultural primacy that science had been enjoying for two centuries world-wide, and in the West for two millennia.[1]

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The first two sections of this article employ the split categories of science and technology to examine Forman's claim. After following Forman's pendulum swings, the third section lumps these categories to provide a balance. The final section suggests some benefits that accrue, particularly for Christians honoring this balance.

Primacy of Science in Modernity

Forman claims that prior to 1980, modernism lumped technology and engineering in with science. Science covered all technical disciplines. It was not simply an umbrella term for a collection of related categories; it was a hierarchical term, signifying that science was the sole basis of technology. Technology was subservient to science. Arie Leegwater describes this approach: "Technology is seen as being, at best, applied science … the conventional view perceives science as clearly preceding and founding technology."[2] He then identifies the genesis of this viewpoint to be historians of science, though he notes that recent "studies in the history of technology have begun to challenge this assumed dependency of technology on science."[3]

Henry Petroski illustrates the subservient relationship by examining media coverage that is often positive for scientists and negative for engineers. When Wen Ho Lee is alleged to have stolen nuclear security data, he is an "engineer," but he is a "scientist" when defended as a victim of bias. When a scientist does work that draws controversy, the headline reads, "Engineering by Scientists on Embryo Stirs Criticism." When radio contact with the Mars Pathfinder mission is disrupted, engineers scramble to solve the problem, but scientists get attention when the problem is fixed. In the 1950s, engineers protested that when a rocket launch was successful, it was a "scientific achievement," but if not, it was an "engineering failure."[4]

Petroski's lament is not a new phenomenon. Shapin describes how the gentleman scientist Robert Boyle relied largely on servant technicians:

> … it is more than likely that very few … of Boyle's experiments involved the laying of his hands upon experimental apparatus or materials. A very substantial proportion of Boyle's experimental work was done on his behalf by paid assistants.[5]

Yet Boyle gives no recognition to their work, considering them largely invisible servants—unless there was a problem.

> Boyle was frequently absent from his laboratory on other business for extended periods, during which he devolved the whole responsibility for managing and recording experiments to his assistants … when the outcome accorded with expectation, no observing agent was customarily specified … Technicians' roles as observers and recorders were alluded to mainly when inconsistent or problematic results were obtained.[6]

The modern primacy of science has vestiges in our postmodern world. A remnant is found in many high schools, colleges, and universities that still reflect the former dominance in the names of their programs and departments. At my home institution, the Division of Natural Sciences and Mathematics omits engineering from its name despite the fact that engineering accounts for a plurality of division majors (and, combined with nursing, accounts for more division majors than all the natural sciences and mathematics combined).

A remnant is also found in the name of this journal's parent society, the American Scientific Affiliation (ASA), which presumes that its name encompasses both science and engineering, both scientific knowledge and technology. The ASA website provides a self-description which first centers on integrating Christian faith with science, describing science as a "way of knowing about [God's natural] order in detail." It then acknowledges a second task: examining "how best to use the results of science and technology."[7] This is a telling juxtaposition of knowledge for edification of the saints with a functional definition that makes science a means to practical ends—and suddenly the word technology appears with the apparent actor being the scientist and no mention of the engineer. The subsumption of technology into science is not simply an artifact of past ASA tradition. Even today, the executive director describes "sciences" to inherently include "all science and engineering and technology vocations."[8]

Primacy of Technology in Postmodernity

Philosophers of technology do not consider their subject to be merely applied science, and many philosophers of science have come to share this opinion. "Certainly the view … that science discovers and technology applies will no longer suffice."[9] Forman claims this shift occurred after 1980, resulting in a postmodern hierarchical ordering. Now technology subsumes and encompasses science. In this section, we will observe the transition from several perspectives: definitions, ordering, knowledge concepts, goals, constituent components, and comparison to other disciplines.

Definitions

Erasmus said that "every definition is dangerous." Typical descriptions of the scientific method (the practice that results in scientific knowledge), such as "systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses,"[10] are virtually unrecognizable as descriptions of engineering (the practice that results in technology). Science as an umbrella term is thus problematic:

> … science is commonly understood to include medicine, engineering, and high technology. "Science" is clearly a useful shorthand for a wide range of activities, but it also obscures the differences between them. It gives science a primacy that it may or may not deserve.[11]

Definitions of engineering do not resemble those of science. Vincenti says engineering is

> the practice of organizing the design, production, and operation of an artifact or process that transforms the physical world to some recognized human end.[12]

Dym describes engineering as

> a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.[13]

The president of the National Academy of Engineering defines engineering succinctly as "design under constraint."[14] None of these definitions mentions science nor restricts engineering to only science. By contrast, Van Poolen's definition states,

> Whereas science discovers the laws of what is embedded in natural, created reality, design embeds into reality the "laws" of various tools and products. In short, science describes the natural while design develops the artificial.[15]

One aspect that all of these definitions omit is a consideration of design as a problem-solving activity, problems that are typically underconstrained, so that trade-offs are necessary and optimization is possible.

The phrase "science and technology" is awkward: science is a practice; technology is a tangible object.[16] The scientist performs the activities of science, experimenting, theorizing, hypothesizing, and so forth. These activities result in scientific knowledge, theories, or, simply termed, science. The engineer performs the activities of design, trade-offs and optimization under constraint, and invention. This activity results in technical artifacts, products, processes, or, simply termed, technology. Not all philosophers of technology hold to a merely material definition. For example, while observing that most definitions of technology include physical attributes (pointing to their status as objects), Van Poolen expands the identity of technology to include attributes of relationship.[17] In doing so, he consciously follows Bruno Latour, who considered technology not to be a thing, but rather a quasi-object—a concept Latour later developed into actor-network theory.

Sequencing

Modernism considers science to be prior to technology in the sequence of development of cultural artifacts (including an assumption that science produces technology); postmodernism assumes a more fluid, nonlinear relationship. Leegwater is helpful here in identifying three ways that science relies on technology. Two are important: (a) providing metaphors for understanding, and (b) use of technological instruments and apparatuses. The third is decisive: (c) "use of technologically developed objects in scientific work." He observes that many significant technological achievements of the Middle Ages

> ran far ahead of the limited scientific knowledge of the time … it was technical, practical machines that preceded and stimulated such scientific theories.[18]

This reversal, to have technological products spur scientific discovery, stands in opposition to modernism's view. Watt's steam engine preceded much of our scientific theory in the field of thermodynamics; indeed, it spurred later scientific research to develop theories explaining the extant engine. Astronomy flourished after the invention of the optical and radio telescope.

Martin Heidegger pushes the reversal even further.

> It is said that modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science. Meanwhile we have come to understand more clearly that the reverse holds true as well: Modern physics, as experimental, is dependent upon technical apparatus and upon progress in building of apparatus.[19]

He goes on to surmise that while modern physical science began chronologically before "machine-power technology," technology precedes science in its "essence holding sway within it."[20] William Lovitt, in translating Heidegger, attempts to explain this phrasing in his introduction to the book:

> *Techné* was a skilled and thorough knowing that disclosed, that was, as such, a mode of bringing forth into presencing, a mode of revealing.[21]

Science might then be more aptly called applied technology.

Writing just after Forman's chronological division of 1980, Leegwater presciently envisions both interpretations of sequencing. He suggests that an examination of engineering science and scientific technology can provide helpful insights into the interaction between science and technology. Even though he provides an example of technology preceding development of the associated scientific principles (Watt's steam engine), he downplays it, saying that while Watt might not have used scientific knowledge, he still used scientific methods to experiment systematically with engine designs.[22] Later, Leegwater notes the mathematical proportions provided in an 1842 book on the engineering and design of waterwheels, describing them as

> certainly not derivable from the principles of mechanics—that is, from abstract scientific theories and knowledge—but they are the result from borrowing and utilizing the methods of science to found new technological sciences.[23]

In attempting to explain technology developed without direct scientific knowledge as its basis, Leegwater points out the more tenuous connections between the two.

However, is it not curious that Watt uses so-called scientific methods to produce not science, but technology? For Watt the engineer, his use of the scientific method was no more definitive than his use of a wrench, blueprint, mathematical formula, or chemical recipe. If the use of a tool defines the user, then teachers would be called applied chalk artists and scientists would be called applied mathematicians or even applied technologists. Later, Leegwater is more sympathetic:

> Science cannot be viewed as the father of technology. Technology is not reducible to the application of prior scientific knowledge. The doing of technology builds up its own repository of knowledge—knowledge of skills, methods, techniques, and designs that do or do not work. The knowledge often precedes and transcends scientific knowledge and explanation.[24]

While one might expect scientists themselves to consider science primary, why would historians of science, whom we might expect to be more objective about science as a social phenomenon, also fall into an indiscriminating sequencing of science before and over technology, despite clear counterexamples? Petroski offers one explanation:

> … our Western Platonic bias has it that ideas are superior and prerequisite to things. Hence, scientists who deal in ideas, even ideas about things, tend to be viewed as superior to engineers who deal directly in things. This point of view has no doubt contributed to the mistaken conclusion that science must precede engineering in the creative process. In fact, … the engineer can go a long way in creating what never was without a fully formed science of the thing."[25]

Leegwater comes to a similar conclusion, noting that liberal arts support of science was of a theoretical nature that disdained "vulgar mechanics" and idealized the "life of the mind."[26]

Body of Knowledge

Engineering has its own body of knowledge independent of science: heuristics, rules of thumb, design processes and procedures—all targeted at optimizing practical value to meet human needs. Joseph Pitt argues that this knowledge is more reliable, implying a primacy for technology.

> On the very grounds on which the claim of superiority is made for scientific knowledge, engineering

> knowledge is shown to be far more reliable than scientific knowledge—thereby exposing the lie in the traditional view that science is our best and most successful means of producing knowledge.[27]

Even for those most opposed to a postmodern primacy of technology over science, Forman observes that they defend the purity of scientific knowledge and justify its truth by validating it thus: "science works."[28] But this defense undermines their position, shading science under the canopy of technology's practical approach.

Purpose

If the purpose of science is the "acquisition of knowledge," as *Responsible Technology* puts it, and the purpose of engineering science is only the "creation of objects,"[29] then science appears more sublime. But most engineering is not merely mass production of bric-a-brac. Technology is always a means to an end. Engineers do not develop devices whose only purpose is to exist. They pride themselves on practical application, on meeting human needs. They test their prowess by the market: those products that sell because they meet a need are considered successful; those that do not are failures. Considering these distinctive incentives, Louis Bucciarelli concludes, "Because their motivation (and rewards) and subject matter differ, engineers think in ways different from those of scientists."[30]

Science eschews subjective values, but values are the objective of engineering. A scientist does not study a new species or subatomic article in order to make it fit some need or solve some problem—in fact, bringing self-interest into the study would be considered a loss of objectivity and thus unscientific. By contrast, "unlike the scientific method, design methodology intentionally incorporates the values of the constituencies."[31] The engineer searches for the best means to solve a problem, inherently self-interested in practical application.

Forman quotes scientist Joseph Henry, saying, "We leave to others with lower aims and different objects to apply our discoveries to what are called useful purposes," and then he concludes,

> Today, in postmodernity, Henry's cynosure of for-its-own-sake science is without cultural understanding or support. Consequently, those who identify themselves as scientists have, overwhelmingly, no other ambition than to place themselves in the service of "useful purposes." To be sure, cosmic-discovery science and history-of-life-on-earth science continue, but less as exceptions than as "useful" to an increasingly credulous, "spirituality"-oriented, romantic-illusionary, postmodern culture.[32]

This reversal goads science to adopt the means-directed, purpose-driven practicality of engineering. Indeed, applicants for today's scientific grants are judged largely on anticipation of utility. Leegwater perceives it so: "The technological needs and desires of society often set the agenda for scientific research."[33] The search for pure knowledge for its own sake may have once been sufficient, but such lofty yet esoteric goals rarely get funding these days. In the decades before Forman's turning point from the dominance of science to that of technology, perhaps there was more room for pure science. But surely, even in the prior decades, government funding came at the cost of showing practical value. Even research with no apparent application that resulted in new knowledge could be held up for national pride. The superpowers' race to space was for patriotic ego as much as it was for national defense. Americans were wrenched into an avid pursuit of science because of the embarrassing bleep of Sputnik circling above—humanity's first artificial satellite produced by the Russians. Thus the cold war provided a purpose even for pure science: it was part of the competition to surpass the other superpower.

Science as One Tool of Many

Engineers do not rely solely on science to ply their trade. They use whatever works. When science provides vague or contradictory guidance, engineering develops its own predictive models and its own guidance to produce technology that performs the needed function. Because science is simply one tool among many, reliance does not indicate subservience. "Science is a tool of engineering, and as no one claims that the chisel creates the sculpture, so no one should claim that science makes the rocket."[34] Engineering even dares to disdain science as impractical—project managers admonish engineers to focus on the end goal without wasting time, by saying, "Don't make it a science project" (with the implication that science takes too long to arrive at a useful result).

The technologist's predilection for practicality has seeped into other professions. A recent issue of *The Atlantic,* concerning the apparent success of some alternative medicine therapies despite no evidence in controlled scientific experiments, notes,

> Rather than going ballistic when they hear that patients believe themselves to benefit under the care of alternative practitioners, argues the Mayo Clinic's Victor Montori, doctors ought to be praising, or at the very least tolerating, alternative medicine for the way it plugs gaping holes in modern medicine. "Who cares what the mechanism is?" he says. "The patient will be healthier."[35]

Montori works in the clinic's Knowledge and Evaluation Research Unit. For him, the reliability of knowledge is about utility: what works is true.

Closer Comparisons

Is science the most similar discipline to engineering? Leegwater points out some similarities between "engineering science" and "basic science" that include conformance with physical laws, tenets "built up and disseminated through similar cultural means such as textbooks,"[36] and cumulative structures built on previous knowledge. It is interesting that "engineering science" rather than the whole body of engineering knowledge is used for the comparison. Furthermore, these same similarities could be used to describe the similarity of engineering to mathematics, medicine, or even music. Besides scientific knowledge, engineering also leverages economics, mathematics, psychology, politics, law, and sociology, to name a few. Petroski has identified these closer cousins (and notice the echoes of Montori):

> Both medicine and engineering do use scientific knowledge and methods to solve relevant problems, but neither of them is simply an applied science. In fact, the practices of medicine and engineering are more like each other than either is like unqualified science: medical doctors and engineers both welcome all the relevant science they can muster, but neither can wait for complete scientific understanding before acting to save a life or create a new life-saving machine.[37]

Because technology has public safety implications, engineers are often licensed in order to practice, placing engineering closer to professions such as medicine or law than to science.

Science and Technology as Improvisational Duet

Both modernism and postmodernism provide all-encompassing historical narratives. Consider Latour. He identifies a shift away from compartmentalized disciplines with their own definitions and priorities toward a more interactive, interconnected network of actors. Simultaneously, he reinterprets historical events, no longer viewing them as simple, pure science, but rather as socially constructed knowledge largely dependent on practical technological devices. For example, he praises a historical study of Boyle that brings

> universal application of a law of physics back within a network of standardized practices. Unquestionably, Boyle's interpretation of the air's spring is propagated—but its speed of propagation is exactly equivalent to the rate at which the community of experimenters and their equipment develop. No science can exit from the network of its practice.[38]

Revisioning Boyle in postmodern (or perhaps anti-modern) terms, Latour makes the claim that forms the title of his book, namely, that we were never modern in the first place.

While Latour develops the idea of social constructivism by expanding the network out from science and technology to "facts, power, and discourse," my focus remains on the concomitant interplay of science and engineering, and their respective results, scientific knowledge and technology. Leegwater acknowledges this relationship:

> Scientists sometimes do technology, and technologists sometimes do science. The contemporary interaction between basic science and technology has therefore resulted in a diversity of activities.[39]

The social constructivists also see this, but recognize that the boundary is fuzzy—a matter of cultural definition:

> Science and technology are both socially constructed cultures and bring to bear whatever cultural resources are appropriate for the purposes at hand. In this view the boundary between science and technology is, in particular instances, a matter for social negotiation.[40]

Don Ihde describes a reframing of the primacy question that "will examine a more symbiotic technology/science direction." [41] He uses the term "technoscience" to name this new détente. However, Forman believes technoscience describes the entanglement of science and technology but does not anticipate their possible equality, suggesting the need for a better label than symbiosis provides.

What name do we give to this interplay? One possibility comes from the National Science Foundation (NSF). Created in the modern era (1950), the NSF of yesterday subsumed engineering and technology, but today recognizes them as equal partners, stating that its mission includes "fundamental fields of science and engineering"[42] and in a strategic focusing on STEM (Science, Technology, Engineering, and Mathematics) education. While the acronym distinguishes the terms, the STEM Education Coalition then lumps these different vocations back together under the technology rubric, in a postmodern move, with its mission to represent "all sectors of the technological workforce—from knowledge workers, to educators, to scientists, engineers, and technicians."[43]

Although STEM is an easy acronym to capture the disparate but related areas, it provides little insight into the relationship. If neither science nor engineering is superior to the other, if neither contains the other, then how do we describe the connection? As early as 1934, we see suggestions that the two are in a collaborative and roughly equal partnership. Historian Arnold Toynbee characterized the association of science with technology (embodied by the Industrial Revolution):

> Since the Industrial System, in its non-human aspect, is based on Physical Science, there may well be some kind of "pre-established harmony" between the two; and so it is possible that no violence is done to the nature of scientific thought through its being conducted on industrial lines.[44]

Toynbee adds a footnote:

> Physical Science and Industrialism may be conceived as a pair of dancers, both of whom know their steps and have an ear for the rhythm of the music. If the partner who has been leading chooses to change parts and to follow instead, there is perhaps no reason to expect that he will dance less correctly than before.[45]

This analogy of dancing partners is picked up thirty years later by Derek J. de Solla Price, a historian of science, who mentions the Toynbee quote;[46] thirty years later still, Arie Rip, a philosopher of science and technology, makes use of the idea.[47] (I am thus a little early to repeat it after only twenty years.) The dancing partners analogy is apt, but limited. Latour mentions the analogy of divided government: the branches of legislative, executive, and judicial form a single institution but interact in a balanced tension to produce, one hopes, the best governance.[48] We might also describe the two as musicians in a jazz band—though accomplished on their own and capable of a solo performance, they combine to produce a musical duet that is richer than the individual strains.

Dance, government, jazz duet—whatever we call the relationship—our label should suggest the nature of the connections between science and engineering (and between their respective results, scientific knowledge and technology). Rip suggests three aspects:

> a laboratory effect or method is exploited for another purpose, … Or a new domain of nature is opened up in the laboratory, and then also available for technical exploitation … [or] science may be a source of powerful heuristics for technological search processes.[49]

Ihde suggests that the interplay between science and technology would be a reframing that

> ends up being multicultural, occurring in many different places and times, and is developmental, particularly with respect to the refinement and progression of the technologies used in producing the knowledge entailed.[50]

It is also worth noting that our dancers or musicians can occasionally swap roles: "… if the natural scientist does have the ability to shape the object of research, and does so, then he or she is doing engineering."[51] Thus we see that the two are not completely distinct; either can carry the melody or harmonize with the other. However, this overlap ought not lead us back to considering one primary.

> Although there may be commonalities in principle and similarities in method, neither science nor engineering can completely subsume the other. This is not to say that self-declared or designated scientists cannot do engineering, or that engineers cannot do science. In fact, it may be precisely because they each can and do participate in each other's defining activities that scientists and engineering—and hence science and engineer—are so commonly confused.[52]

This interchangeability may mean that Van Poolen's line between the natural and the artificial is rather fuzzy.[53]

Why It Matters—Particularly for Christians

This final section offers a few reasons why the interplay of science and engineering is important, especially to Christians. From an engineering viewpoint, this section is about practical design: how are these tools means to a desired end? From a science viewpoint, this section is about inquiry: how do these practices lead to deeper knowledge?

Van Poolen writes that the Enlightenment has pushed us to reductionism, splitting complex meaning into simpler and simpler building blocks. But in interpreting technology, he says we have moved up levels of complexity (e.g., from bolts sitting on a shelf to bolts fastening together a complex bridge[54]), looking at the complex whole, leading to a unity in Christ.

> Ultimately, we can view technological things in a meaningful way because of the overall structure of relational unity given in the divine/human Word, the Logos. In this larger relational unity, the relational character of the quasi-object, hermeneutical text, and localized logos point us towards a Christian theory of technological things as containers for information about ourselves: who we are and what we value.[55]

While unity in Christ is certainly a biblical principle, it is not obvious that the three relational traits named by Van Poolen lead singularly to this conclusion. The characteristics are not necessarily distinctive to Christian faith. However, the author is clear that this is simply a starting point, hinting that this distinction is found in the connections:

> … meaning is found more in relationships between and within things than in the things themselves. This is suggested as an area ripe for further investigation within a Christian perspective.[56]

I hope that the following thoughts contribute to that investigation, focusing on three benefits that derive from recognizing the interplay of science and engineering: (1) the dance suggests diverse ways to worship God, (2) the dance helps us avoid idolizing "-isms," and (3) the dance helps us understand our roles as stewards.

More Ways to Worship God

Simply recognizing the distinct and equal partners is a point of respect and thus justice, so that the dance itself can be a form of worship.

We worship by appreciation. Scientific discoveries extend our understanding of the natural creation, which can lead us to better value its beauty and complexity, which in turn lead us to appreciate the Creator. When we discover a new space object or a new chemical or a new species, we worship. When we discover new elements of creation, we are unwrapping the gift of creation a bit further, providing us with new opportunities to give God the glory for the wonder of the world he created. So whereas Forman declares that science for its own sake in pursuit of knowledge has become "depreciated,"[57] Christians can, on the basis of their faith, redeem the scientific pursuit of pure knowledge, restoring a sense of wonder and awe of God's creation.

We worship through stewardship. Called to care for creation, we are the protectors and preservers of the natural world around us. Proper care requires appreciation, understanding, and judgment, so that we know how to be stewards of natural resources. This understanding comes largely from science. Yet, passive knowledge is not sufficient. We are not called to keep creation in a static, untouched state. As stewards, we are called to cultivate the creation, to develop culture that thoughtfully and appropriately uses the gift of creation. Creation is sometimes like the gift of a beautiful painting that we are free to observe but ought not touch. More often it is like the gift of an Erector Set™ or Lincoln Logs™ that we appreciate not only by reading the instructions, but also by building new and interesting designs from the basic elements it provides.

We worship through development. Technical development is part of God's mandate to develop culture (Gen. 1:28). When discovery turns to development of features that do not occur naturally, then science has morphed into engineering and our results are not simply the understanding of an existing aspect of creation, but a wholly new invention. Rather than take credit, we give God glory for providing raw materials that can be combined in new ways. This, too, is an unwrapping of the gift of creation. From the simplest cultivation of a garden on a hillside to the most complex genetic engineering, from the crudest hammer made with stone tied to wood to the most sophisticated medical instrument, we unfold the creation when we create. Our human ability to create is a reflection of our Creator. Made in his image, we are given a special gift to create, though limited to reworking existing matter and energy, rather than creation *ex nihilo*.

Avoid Idolizing "-isms"

Besides leading us toward God in worship, the dance can also keep us from straying toward philosophical idols. The interplay of science and technology helps us to avoid putting our faith in science or technology (scientism or technicism). Either could serve as an idol, and their combined power could be more alluring yet. Distinguishing between science and technology helps us reframe our trust by the interplay of primacy. Which came first? Which drives which? This fluid relationship between the two provides a healthy corrective, lest we settle into a comfortable trust in science as the ultimate arbiter of truth or in engineering as the ultimate test of what works. Instead, we place fundamental trust in God to uphold his creation providentially.

The interplay of science and technology can help us avoid technical neutralism. The scientist is supposed to be objective and disinterested when performing experiments to prove or disprove a hypothesis; science is supposed to be pure and free of bias. In reality, scientists have certain cultural dispositions: power and politics and money can sway the direction of research. Likewise, the engineer is supposed to be neutral; technology is supposed to be an unbiased means to an end. In reality, the engineer is designing according to values that are self-identified or driven by a customer; the technological product has built-in bias that can have a subtle influence on what the tool can do.[58] The separate but overlapping identities of science and engineering are best distinguished by their purpose. Uncovering motivation and goals highlights underlying values. Once brought to light, we can evaluate research directions and strategic technological developments on the basis of scriptural principles.[59]

The interplay helps us avoid determinism. If we believe that we are simply cogs in the gears of science or industrialism, then we easily abdicate responsibility. Today's enterprise prizes niche skills, producing a factory-like narrowing of scope.

> Inventors, industrial scientists, engineers, managers, financiers, and workers are components of but not artifacts in the system. Not created by the system builders, individuals and groups in systems have degrees of freedom not possessed by artifacts. Modern system builders, however, have tended to bureaucratize, deskill, and routinize in order to minimize the voluntary role of workers and administrative personnel in a system.[60]

Science may be objective (or at least appear so), but the scientist is not a helpless minion deterministically pursuing a prearranged fate. Choices can be made, and this becomes clearer in engineering design. The dance between science and technology can help us reestablish our human freedom to direct our own steps, so that we take back responsibility for the direction of development.

The interplay helps us avoid modernism's conceit. The allure of science—that can turn to positivism—and the temptation of technology's power—that can turn to arrogance—are tempered because science needs technology and technology needs science. There is no simple, sequential process that leads to progress. To avoid the danger of the combined dance leading to hubris, it is important that the two partners act as a check and balance on each other. Science explores the full implications of technological products; technology helps us focus on the truly good ends to which we direct our means.

The interplay helps us avoid postmodernism's despair. Relativism and deconstructionism hurl us into rough seas with no anchor and no solid landmarks by which to navigate. Our science and technology are both called into question as social constructions. However, like Samuel Johnson's famous refutation of Berkeley's immaterialism, "striking his foot with mighty force against a large stone, till he rebounded from it, 'I refute it thus.'"[61] Technology provides evidence of its own veracity as well as for the scientific principles it embodies, by virtue of the fact that it works. Engineers and scientists do not deconstruct the design of a bridge nor tolerate every design as equally valid social interpretations. Some bridges work and others do not.

Understand Our Role as Stewards in Directing Science and Engineering

Science and engineering can be pursued for a variety of reasons: pursued for their own sake, their beauty, and their lasting endurance; pursued as a job and a source of income; pursued for glory, fame, or power. What is our proper role as Christians in these vocations? Consider an analogy from technology, using Carl Mitcham's framework for the modes of the manifestation of technology: technological objects (or artifacts), technological activities (making and using), technological knowledge, and technological volition.[62]

In naming volition, or will, as an aspect of technology, Mitcham recognizes the culture-making potential of technology, and furthermore, the power of the tool that extends our desire—physical and also political power. Technology as prideful volition, as the metaphoric tool in our hand, makes us the captain of our own fate. Masters of our own destiny, we scoff at a higher power, finally shaking off the fates that capriciously control our lives. We are the tool-maker and the tool-wielder. We can rationalize that objectivity and neutrality make our cause obviously right because it is scientific, yet, in reality, science and engineering too easily become our means to power and control over nature—and over each other. But our faith speaks otherwise. We are the tool. Our Creator God made us; he is the Potter, and we are the clay. We are thus instruments of his peace. As God's steward of God's creation, we are the means to God's ends for the creation to flourish, acting as his hands. Scientific knowledge and technology amplify our ability to be good stewards. Just as they can check and balance each other to prevent pride, they can also help guide our cultural development, giving us clear-eyed assessments of our impact on the environment and on each other.

Conclusion

Modernism and postmodernism both get it wrong. Science and engineering are related, but distinguished, activities that, when done well, can reinforce and invigorate one another, to God's glory. Let neither science nor engineering be a slave to the other, because when they dance as equal partners, the result is deeper insight and richer worship. Shall we continue to dance together? ✦

Notes

1Paul Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," *History and Technology* 23, no. 1 (2007): 2.

2Arie Leegwater, "Technology and Science," in *Responsible Technology: A Christian Perspective,* ed. Stephen V. Monsma (Grand Rapids, MI: Eerdmans, 1986), 78. Arie Leegwater is one of the coauthors of this edited book. Where the authorship of a particular section is known, the specific author will be listed.

3Ibid., 79.

4Henry Petroski, *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (New York: Alfred A. Knopf, 2010), 26–8.

5Steven Shapin, "The Invisible Technician," *American Scientist* 77 (1989): 557.

6Ibid., 558.

7"About ASA," http://www.asa3.org/index.php?option=com _content&id=86.

8Randall D. Isaac, Executive Director of the ASA, private communication, 14 Sept. 2011.

9Trevor Pinch and Wiebe Bijker, "The Social Construction of Facts and Artefacts: Or, How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," *Social Studies of Science* 14, no. 3 (1984): 403.

10http://oxforddictionaries.com/definition/scientific+method.

11Petroski, *The Essential Engineer*, ix.

12Walter G. Vincenti, "Engineering Knowledge, Type of Design, and Level of Hierarchy: Further Thoughts about What Engineers Know," in *Technological Development and Science in the Industrial Age: New Perspectives on the Science–Technology Relationship,* ed. Peter Kroes and Martijn Bakker (Dordrecht: Kluwer Academic, 1992), 18–9.

13Clive L. Dym et al., "Engineering Design Thinking, Teaching, and Learning," *Journal of Engineering Education* (January 2005): 104.

14William Wulf, quoted in Fiona Clark and Deborah L. Illman, "Portrayals of Engineers in 'Science Times,'" *IEEE Technology and Society Magazine* (Spring 2006): 14.

15Lambert Van Poolen, "A Design Philosophy," in *Responsible Technology,* 166.

16We commonly think of technology as an object or device, but it is true that some nonphysical developments are also technology, such as an encryption algorithm or a manufacturing process. The authors of *Responsible Technology* define it as a "cultural activity" rather than the objects we commonly call technology. I prefer to call the activity, "design" or "engineering," and call the result, "technology."

17Lambert Van Poolen, "Towards a Christian Theory of Technological Things," *Christian Scholar's Review* 33, no. 3 (Spring 2004): 367–8.

18Leegwater, "Technology and Science," 86–7.

19Martin Heidegger, "The Question Concerning Technology," in *The Question Concerning Technology and Other Essays,* Martin Heidegger, trans. William Lovitt (New York: Harper and Row, 1977), 14.

20Ibid., 22.

21William Lovitt, "Introduction" in *The Question Concerning Technology*, xxv.

[22]Leegwater, "Technology and Science," 90.
[23]Ibid., 92.
[24]Ibid., 94.
[25]Petroski, *The Essential Engineer*, 24.
[26]Leegwater, "Technology and Science," 81.
[27]Joseph C. Pitt, "What Engineers Know," *Techné* 5, no. 3 (2001): 17.
[28]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 13.
[29]Leegwater, "Technology and Science," in *Responsible Technology: A Christian Perspective,* 93. The author compares the goals of science with engineering science, rather than engineering more broadly (the goals of which are never explicitly identified).
[30]Louis L. Bucciarelli, "Engineering Science," in *A Companion to the Philosophy of Technology*, ed. Jan Kyrre Berg Olsen, Stig Andur Pedersen, and Vincent F. Hendricks (Chichester, UK: Wiley-Blackwell, 2009), 67.
[31]Jack C. Swearengen, *Beyond Paradise: Technology and the Kingdom of God* (Eugene, OR: Wipf & Stock, 2007), 194.
[32]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 11.
[33]Leegwater, "Technology and Science," 94.
[34]Petroski, *The Essential Engineer*, 45.
[35]David H. Freedman, "The Triumph of New-Age Medicine," *The Atlantic* (July/August 2011): 99.
[36]Leegwater, "Technology and Science," 93.
[37]Petroski, *The Essential Engineer*, ix.

[38]Bruno Latour, *We Have Never Been Modern*, trans. Catherine Porter (Cambridge, MA: Harvard University Press, 1993), 24.
[39]Leegwater, "Technology and Science," 94. Leegwater implies that technology is a practice (since one can "do" it), while I prefer to use the more commonly understood usage, making technology the object and result of the practice of engineering.
[40]Pinch and Bijker, "The Social Construction of Facts and Artefacts," 404.
[41]Don Ihde, "Technology and Science" in *A Companion to the Philosophy of Technology,* 57.
[42]"US NSF—About the National Science Foundation," http://www.nsf.gov/about/.
[43]Home page of STEM Education Coalition, http://www.stemedcoalition.org/.
[44]Arnold J. Toynbee, "Introduction: The Geneses of Civilizations," *A Study of History*, vol. 1 (first ed., 1934; New York: Oxford University Press, 1962), 2–3.
[45]Ibid., 3, footnote 1.
[46]Derek J. de Solla Price, "Is Technology Historically Independent of Science? A Study in Statistical Historiography," *Technology and Culture* 6, no. 4 (Autumn 1965): 553–68.
[47]Arie Rip, "Science and Technology as Dancing Partners" in *Technological Development and Science in the Industrial Age,* ed. Peter Kroes and Martijn Bakker (Dordrecht: Kluwer Academic, 1992), 231–70.
[48]Latour, *We Have Never Been Modern*, 13.
[49]Rip, "Science and Technology as Dancing Partners," 236–7.
[50]Ihde, "Technology and Science," 57.
[51]Bucciarelli, "Engineering Science," 67.
[52]Ibid., 26.
[53]See Rip, "Science and Technology as Dancing Partners," who models both scientific knowledge and technological objects as search processes so that knowledge and artifact are on one continuous spectrum.
[54]Van Poolen, "Towards a Christian Theory of Technological Things," 371.
[55]Ibid., 376–7.
[56]Ibid., 377, footnote.
[57]Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," 11.
[58]For further analysis of technological bias, see my paper, Steven H. VanderLeest, "The Built-in Bias of Technology," *Proceedings of the 2004 American Society for Engineering Education (ASEE) Conference* (Salt Lake City, UT: June 2004), 1417–27; also refer to chapter 3, "Is Technology Neutral?" of *Responsible Technology*.
[59]Steven H. VanderLeest, "Virtuous Design," *Proceedings of the 2006 Christian Engineering Education Conference* (Bourbonnais, IL: June 2006).
[60]Thomas P. Hughes, "The Evolution of Large Technological Systems" in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, MA: MIT Press, 1987), 54.
[61]James Boswell and Christopher Hibbert, eds., *The Life of Samuel Johnson* (New York: Penguin Classics, 1986), 122.
[62]Carl Mitcham, *Thinking through Technology: The Path between Engineering and Philosophy* (Chicago, IL: University of Chicago Press, 1994), 159–60.