Note on Practical Knowledge

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Working Paper 21-010

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Funding for this research was provided in part by Harvard Business School.

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This Note examines the development of the knowledge embodied in 'artifacts' -- things and arrangements that do not exist in nature. It focuses on 'multi-player' advances – artifacts and knowledge developed by and for the many – and highlights the venturesome spirit and technical scaffolding of such advances. And it suggests ways for using the scaffolding while keeping the sprit.

By traditional and modern standards practical knowledge has low intellectual standing. The ancient Greeks venerated contemplation, music and the other arts, abstract truths, and mathematical reasoning. Merchants and craftsmen occupied the bottom rung of Plato's idealized society; their knowledge and toil were but means for the good life of a small enlightened class. Modern societies now include science in the knowledge they venerate. Engineers, physicians, lawyers, entrepreneurs, managers, and accountants earn high incomes; but many dismiss their knowledge as a mere application of deeper scientific ideas.

Yet, practical advances affirm an essence of our humanity. We are human because we create, not just because we think abstract thoughts. A relentless preoccupation with the development of artifacts that stimulate our senses and minds far beyond any natural physiological need sets our species apart. The artifacts embody human knowledge created through the exercise of human faculties: to imagine, to reason, to have faith and to control our anxieties, to communicate and collaborate.

Our capacity for useful collaborative creativity has expanded vastly over the last hundred years or so. Highly participative and interconnected -- or to put it colloquially -- *massively multiplayer* -- innovation now provides unprecedented scope for individuals with diverse skills, capabilities, and backgrounds to exercise their imagination and initiative.

New techniques provide an essential scaffolding. Massively multiplayer development does not exclude unplanned discoveries. But multiplayer development of new combinations ("ideas having sex" in Matt Ridley's memorable phrase) relies more on careful, selective breeding than on accidental or anonymous encounters. Silicon Valley has produced more than just path breaking technological advances; companies like Intel have also pioneered goal setting systems to coordinate and control employees dispersed across diverse locations and functions.

Watersheds of Practical Knowledge. Scientific discoveries provide a crucial starting point for many technologies. But technology does not just gush out of scientific geysers. Just as much of the water that a river carries into the ocean does not originate in its headstreams, science does not provide all the important knowledge embodied in artifacts. The watersheds of practical knowledge (See Figure 1) include:

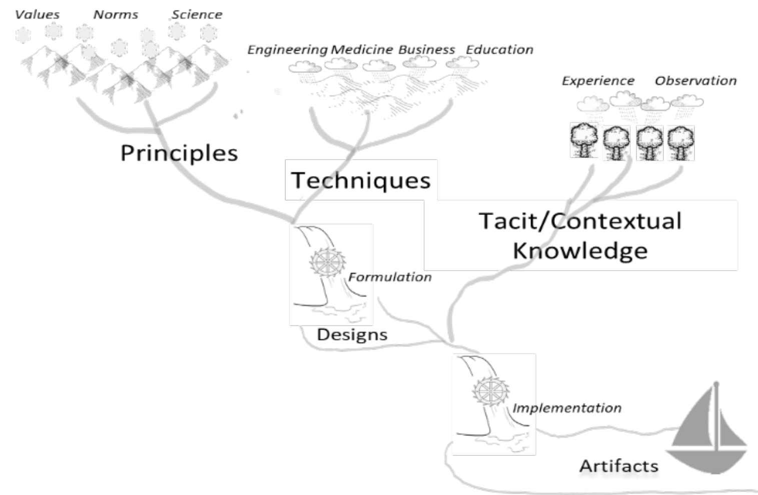
- General principles, often derived from science, individual values, and social norms.
- Systematic techniques, drawn from engineering, medicine, business, education, and other such purposeful fields that help turn general principles into detailed designs.
- Tacit and Contextual knowledge acquired through experience or direct observation that enable implementation of designs in usable artifacts.

Even methods designed for scientific discovery are often ill-suited for choosing "upstream" ends, developing systematic "midstream" techniques, or acquiring tacit "downstream" knowledge.[1]

Meanwhile, the proliferation of techniques for multiplayer development has made identifying the good ones difficult. Application also poses challenges. Techniques must fit the overarching "upstream" goals and detailed local downstream conditions: practices that work well in say Silicon Valley may not suit other

This Note condenses a longer working paper, "Seminar on Practical Knowledge: Sustaining Massively Multiplayer Innovation" (May 25, 2019). Available at SSRN: https://ssrn.com/abstract=3394337 domains without considerable adaption. And, bureaucratically used techniques can suffocate the spirit of innovation which objective knowledge and analytical skills cannot replace.

Figure 1: Watersheds of Practical Knowledge



Guide to a Guide. A National Geographic style guide map would help us choose techniques and reuse exemplary designs. National Geographic maps contain basic information, not the detail of military grade satellite images. Constructing such maps therefore requires deciding what information to provide and how. A river map for instance may have separate pages for the upstream headwaters, middle basins, and downstream deltas. Each page may show the main channels, as smoothed rather than photo-realistically jagged streams, and recreational areas (as stylized icons); but, for clarity and compactness, the map may exclude vegetation on the banks of the river. Guide maps also encourage visits to the places they cover, at least indirectly. Even warnings about grizzly bears and rapids evoke alluring adventures.

This Note offers a template for a similar guide to multiplayer innovation. The "pages" or "sections" of the guide would consist of common 'tasks' and include popular techniques used to perform the tasks (see Table 1). The guide would also include case histories, that like the pictures and descriptions in a river or mountain guide, show the romance of developing new artifacts. It would thus inform and inspire.

The next sections describe the:

- Spirit and essential ('primordial') tasks needed to develop artifacts.
- Advantages and challenges of 'multiplayer' development.
- Analytical framework for examining common multiplayer tasks and techniques.
- Benefits of studying case histories of transformational artifacts.

A concluding appendix examines the contrasts between scientific knowledge and techniques for developing artifacts.

Table 1: Common Tasks and Techniques	
Tasks:	Examples of Techniques:
Specify Goals (and sub-goals)	Objective and Key Results; Journey Maps
Conjecture	Positive Deviance; Root Cause Analysis
Evaluate and Test	Randomized Control Trials; Rapid Prototyping
Codify	Checklists; Best Practice Programs;
Communicate	Pyramid Principle; Social Media Marketing
Commit (to Strategic Goals and Policies)	SWOT, Five-Force Frameworks
Assign (Responsibility and Authority)	Organizational Templates; Project Management
Motivate ("Incentivize")	Salary surveys; Job Enrichment

Spirit and Essential Tasks

Willful Quest

Genetically encoded biological evolution provides an instructive contrast for the development of the knowledge embodied in artifacts. Like genetic information, the knowledge is multifarious and serves numerous functions. For instance, making and selling a simple analgesic like ibuprofen, requires knowledge spanning technical specifications (how many milligrams of active ingredient, binding agents, coatings etc.), sourcing, manufacturing and quality control, logistics, packaging, advertising, and regulatory compliance. Just as genetic information evolves to encode more complex life-forms – from single-celled organisms to humans – new knowledge supports more sophisticated artifacts – from sundials, to pendulum clocks, to ship chronometers and pocket watches for instance. Moreover, as with genetic information, the knowledge expressed in transformational artifacts evolves through the extended accretion of changes, and not in a single bound.

But whereas time can make humans from primordial soup through mutations that occur without any purpose or end, the development of artifacts requires applying will, imagination and reason to perform several *tasks*.

We choose short and long-term *goals* for the wants we want to satisfy.

We form *conjectures* about how we might attain our goals and make willful choices about how to *evaluate and test* these conjectures.[2]

Successful ideas diffuse through deliberate *codification* and *communication* (or imitation), not through the unconscious inheritance of mutations.

Commitments to strategic choices and goals guide accretive development -- leaving room for adjustments while maintaining commitments to an overall direction. [*] (See the Box 'Fixed-Wing Flight'.)

Fixed-Wing Flight

The development of fixed-wing aircraft exemplifies persistence with strategic principles while adapting tactical choices. Sir George Cayley first enunciated the underlying conjecture – that propelling a rigid surface through the resistance of air could produce an upward force ("lift") that would offset the downward pull of gravity – in 1809. All "airplane designers have this concept at the back of their minds" now, writes Walter Vincenti (former chair of Stanford's aeronautical engineering department), but Cayley's concept was "revolutionary at the time" because it "freed designers from the previous impractical notion of flapping wings." Yet, it took nearly a century before the principle produced the first controlled flight of a powered, heavier-than-air aircraft on December 17, 1903, when the Wright Flyer took wing – for all of 200 feet. In the interim, intrepid inventors had experimented with gliders, steam engines, gasoline engines, propellers, automobile chains, and rudders. Otto Lilienthal, who had made the first well-documented, repeated, gliding flights, broke his neck and died in 1896 after his glider stalled. Finally, the Wright Brothers built on these prior efforts, improved on wing materials and designs, and pioneered the "three-axis" system to control flight.

Venturesome Leaps

Farsighted strategies can, however, also come to nothing. It's obvious now that Cayley's principle was sound and that the many failures that preceded the Wright Flyer reflected limitations of wing, airframe, propeller, and control designs. But efforts to develop fixed-wing airplanes, like alchemy, could have been a fantasy. Or, even if technically feasible, fixed-wing aircraft could have lost out to rigid airships, popularly known as "Zeppelins," (summarized in the Box 'The Rise and Fall of Zeppelins'). Similarly, the synthesis of ibuprofen followed the screening of more than 600 compounds over more than ten years; this effort could, like attempts to cure the common cold, have been futile.

The Rise and Fall of Zeppelins

Count Ferdinand von Zeppelin first formulated his idea for rigid airships in 1874. Over the next 20 years he developed the technical details, which he patented in 1895. After several failures and some fatal accidents, airships built by the Count's eponymous Zeppelin Company were put into commercial service in 1910 by Deutsche Luftschiffahrts-AG (DELAG). DELAG, founded in 1909 by Count Zeppelin, thus became the world's first revenue-generating airline. And, by the onset of the First World War, DELAG had carried over 10,000 passengers in over 1500 flights.

Following the war, the Treaty of Versailles then prohibited Germany from building large airships. After the restrictions were lifted in 1926, the Zeppelin Company started building the LZ 127 Graf Zeppelin. Work was completed in 1928 and the Graf (again operated by DELAG) began providing regular transatlantic commercial service in 1930. It was joined in 1936 by the larger LZ 129 Hindenburg. Unfortunately, in 1937, the Hindenburg caught

[*] Willful humans can dismiss favorable options – or even accept unfavorable options – "in order to gain access to even more favorable ones later on." (Elster 1993 p. 91). In contrast, natural selection has an "impatient, myopic, or opportunistic" character. It cannot learn from mistakes because it has "no memory of the past," and no forethought -- it does not forgo favorable mutations now to realize better ones later, as it has "no ability to act in terms of the future." (Elster 1993 p. 51) And nature does not permit willful imitation: house cats cannot follow the hunting habits of tigers. Mutations diffuse entirely as a side-effect of reproduction.

fire in New Jersey after a transatlantic flight, killing 35 of the 97 people on board. The Graf Zeppelin was retired a month later. Thus ended the role of airships in providing commercially viable long-haul air transport that they, not fixed-winged airplanes, had pioneered.

But just as success isn't a forgone conclusion, neither is failure. Invariably, protracted development poses "unmeasurable and unquantifiable risks."[3] Skeptics who bet against new technologies – producers of buggy whips, oil lamps, and sailing schooners, for instance – can be swept away.[4]

Therefore, those who persist – as well as those who do not – have to make choices that, to borrow from the 19th century existentialist Søren Kierkegaard, involve a 'leap of faith.'[5] Moreover, those who first make the leaps also have to recruit others – visionaries rarely undertake the protracted development of artifacts on their own. Moreover, to persuade potentially skeptical supporters, pioneers' own convictions must be exceptionally strong.

Thrift and bourgeois virtues of temperance and prudence celebrated by Max Weber and Deirdre McCloskey as the foundation of modern capitalism have their place — but only when joined to imprudent, against-the-odds audacity.

Consumers also cannot escape venturesome leaps. One simple reason is that different individuals have different tastes and preferences. A best-selling book may not delight all subsequent readers, and patrons drawn to a three-star restaurant may leave disappointed. More subtly, consumers also often must invest in knowledge and infrastructure that unexpected social or technological developments can render worthless. For instance, the inability of Sony's pioneering Betamax video format to withstand the challenge of VHS harmed consumers who had accumulated libraries of Betamax videotapes, just as it did Sony. However, avoiding new technologies isn't safe either: buyers who stuck with sailing ships, like the shipyards who produced them, also lost out. Similarly, while experimental drugs can have dangerous long-term side effects, rejecting new diagnostic techniques (to detect colon cancer for instance) can be life-threatening.

Pragmatic Paradoxes and Combinations

Pragmatist philosophers such as Charles Sanders Peirce, William James, and John Dewey, argue that the significance of ideas lies in their practical utility – "cash value," as James puts it. Where Plato privileged truth that "lies in the abstract and exists more clearly in our minds than in the natural world," the pragmatist asks what works rather than what is true.[6]

Developers of practical knowledge are obviously more pragmatic in favoring the useful over the ultimately true. They also 'paradoxically' combine, as we will see next, 'rationalist' generalization with context-specific 'empiricism' and progressivity with conservatism.

Rationalist Generalization + Context-Specific Empiricism. Pragmatism conjoins, according to James, the opposing dispositions of rationalists and empiricists. Rationalists, in James's classification, are "monists," "devoted to abstract and eternal principles." They "start from wholes and universals and make much of the unity of things." Their truth lies (as in Plato) more clearly in the mind than in the natural world. Empiricists in contrast are "devoted to facts in all the crude variety" (see Box 'Rationalists v Empiricists); they seek, like the fox in Isaiah Berlin's later essay, to know many things rather than the hedgehog who knows one big thing. James's sympathies clearly tilt towards empiricism.

Rationalists v Empiricists

> The empiricists' world of "concrete personal experiences," William James observed, "is multitudinous beyond imagination, tangled, muddy, painful, and perplexed." In contrast, the rationalists' world is "simple, clean and noble. The contradictions of real life are absent from it. Its architecture is classic. Principles of reason trace its outlines, logical necessities cement its parts. Purity and dignity are what it most expresses." But this latter world is just a "sanctuary in which the rationalist fancy may take refuge from the intolerably confused and gothic character which mere facts present. It is no EXPLANATION of our concrete universe, it is another thing altogether, a substitute for it, a remedy, a way of escape."

But crucially, James favors including the abstractions of rationalism when they have practical utility. James's own pioneering work in the then emerging field of psychology was not light on abstractions. Similarly, developers and users of artifacts must pay close attention to both contextual facts in "all their crude variety" without discarding abstractions that can provide a foundation for practical designs. The overhead bins of modern airplanes must be designed to accommodate roller carry-on bags and cargo holds to quickly load and unload checked luggage. Similarly, organizing the production of these artifacts requires knowledge of the quirks and capacities of specific manufacturing plants and suppliers and labor agreements with unions. At the same time, developers of airplanes rely heavily on the abstractions of fluid mechanics and biochemistry – and, as already mentioned, a strategic commitment to fixed wing flight.

Progressivity + Conservatism. Pragmatism also balances tendencies that propel and restrain change. Nineteenth and early 20th century pragmatists implicitly or explicitly embraced efforts to progress: ultimate truths might never be discovered, but advances in knowledge that improved the human condition were always at hand.[7]

Yet in James's telling, pragmatic considerations require respecting existing ideas. James's pragmatist will seek out new ideas only to the degree that old ideas cannot deliver the goods, and, even then, will favor modifying or extending what exists rather than starting from scratch.

A similar combination characterizes the development of artifacts. A progressive conviction that things can be made better, that dogged enterprise can overcome problems, nourishes the leaps of faith necessary to persist through setbacks. Yet, the existing stock of tangible and intangible capital, and social and psychological conservatism, favors retaining what is already known and used to whatever degree is possible.

Overwhelming Choices

Combining grand "monistic" leaps and myriad context-specific decisions create tangles of choices. For instance, developing a self-driving vehicle raises, in addition to the core bet on driverless transportation, questions about goals: what overarching purpose or purposes should the vehicle try to serve: reducing accidents, traffic congestion, driver stress, or labor costs? And, in what priority? Numerous and more specific goal-and-and-objective choices follow, pertaining to vehicle size, target cost, speed and range, reliability and so on. Then, there are even more choices about means: navigational technologies, power sources (battery vs. gasoline), body materials, back-up and monitoring mechanisms, scale of production, financing, marketing, and after sales service and so on.

Simple trial-and-error provides limited help in making these choices. Consider the extreme example offered by Angus Deaton, of his four-year-old granddaughter using trial-and-error to master the popular Angry Birds game (played on mobile phones). The game has features that make trial-and-error effective: a simple goal (to kill as many pigs as possible); very few things that players can manipulate; and immediate and unambiguous feedback.

These features are however absent in the development of most new artifacts. As mentioned, development requires choices about goals and sub-goals – these are not simple 'givens.' Choices about means are complex, and the immediately apparent options are not the only ones potentially available. The developer of a driverless car, for instance, can choose an existing navigational technology or try to invent an alternative – which requires betting on a speculative conjecture. Choices cannot be made one-at-a-time: The target use for a driverless vehicle has implications for factory size and battery-technology choices. And trials cannot provide immediate or unambiguous feedback. No tests can reliably anticipate the long-term, real-world performance of a new driverless vehicle.

If developers could predict the consequences of all possible combinations, of known and unknown options, of grand strategies as well as tactics, problems of real choice would not even arise. Like hydrogen combining with oxygen to produce water, we would simply do the foreordained. But human choices, go beyond cognition. According to Kierkegaard, choice creates existentialist anxieties: Abraham's decision to obey God's command to sacrifice his son produced *Fear and Trembling*. If so, confronting overwhelming combinations of options should, like large leaps of religious faith, create unrelenting anxiety.

Anxiety in turn can encourage "satisficing": pick the first option that alleviates the problem at hand — and only when the problem becomes intolerable. Up to a point, such satisficing is the inevitable result, as Herbert Simon pointed out, of the "boundedness" of our rationality — our ignorance of all the options that might exist and of their consequences. It is also pragmatic in respecting what's known to work: "if it ain't broke, don't fix it." But satisficing emasculates our capacity for foresight, for making choices before we must, and for imagining options that do not naturally appear in front of us. This limits bold leaps and makes pragmatism more conservative than progressive.

Advantages and Challenges of Multiplayer Development

Transformational Widening

As mentioned, the development and use of artifacts has become highly democratized and participative over the course of the last 100 or so years. Although many revolutionary products were invented between 1850 and 1900, new artifacts were usually developed by a few inventors. Alexander Graham Bell invented the telephone with one assistant. Automobile pioneers were one- or two-man shows — Karl Benz and Gottlieb Daimler in Germany, Armand Peugeot in France, and the Duryea brothers of Springfield, Massachusetts. But small outfits could not develop reliable products for mass consumption: early automobiles, expensive contraptions that broke down frequently, were purchased by rich buffs "riding around the countryside terrifying horses."[8]

Innovation then became much more broad-based starting in about the 1920s and continuing through the present. The division and specialization of labor that dramatically increased production efficiency in the early 20th century has now, albeit more quietly, transformed the development of virtually all artifacts. The Internet for instance, does not have a solitary Alexander Graham Bell. Innumerable entrepreneurs, financiers, executives of large companies, members of standard-setting institutions, researchers at universities and commercial and state-sponsored laboratories, programmers who have written and tested untold millions of lines of code, and even investment bankers and politicians – not just a few visionaries or researchers – have turned the Internet into a revolutionary medium of communication and commerce. Steve Jobs, often portrayed as a brilliant solitary inventor, relied on the contributions of tens of thousands of individuals working at Apple and its network of suppliers.

The broadening of venturesome consumption has provided crucial support to multiplayer development. Thomas Edison, the Wizard of Menlo Park, "devoted his talents to providing novelties for the urban upper class."[9] Now millions of the not-so-well-to-do line up to buy Apple's latest offerings. And larger demand pays for the greater specialization of development: In innovation, as in Adam Smith's 18th century pin factories, "the division of labor is limited by the extent of the market." The venturesomeness of contemporary consumers also includes resourceful effort. Complex, feature-rich artifacts – iPads and iPods included – usually don't "just work" out of the box. Producers cannot afford to provide individualized training and instead rely on the resourcefulness of consumers to learn about the quirks and nonobvious attributes of their artifacts. Similarly, consumers modify products standardized for low-cost mass production to suit their individual needs. And some leading-edge consumers participate in the process of development by providing valuable suggestions and feedback to developers.*

Gains from Specialization

Advances in science and technology have helped specialize and broaden multiplayer innovation. Improved scientific understanding of disease mechanisms have helped teams of researchers in pharmaceutical companies establish assembly lines to systematically screen molecules for their potential therapeutic effects, and new print on demand and computer simulation technologies help product design groups rapidly test many physical or virtual prototypes. New radio, television, and internet technologies have helped create large markets that allow more specialization of innovative effort. And, specialization has taken fantasies of talking to watches and driverless cars from fiction to reality as well as transformed traditional industries such as shoemaking. (See Box, 'Running on Air').

Running on Air

Shoemaking was one of the first industries in the United States to specialize and automate production, and by the early 20th century, affordable shoes made in large factories had made owning multiple pairs commonplace. Goodyear introduced "Keds" with vulcanized, treaded soles in 1892, but did not market them as an athletic shoe till 1917. Adolf Dassler began making running shoes in 1920 for competitive runners: Jesse Owens won his Olympic gold medals wearing Dassler shoes.[10] But these innovations did not launch multi-player development of running shoes for mass markets.

In 1960, New Balance Inc. introduced what is thought to be the first mass-produced running shoe, the *Trackster*. The *Trackster* was also the first shoe to be offered in varying widths, increasing its appeal. Then, after Nike pioneered waffle-soled shoes in 1972, and the Brooks Manufacturing Company introduced shoes to control pronation, one product innovation quickly followed another: shoes with proprietary cushioning systems (starting with Nike's Air shoes) and pumps (pioneered by Reebok) as well as minimalist, ultralight shoes weighing less than 3 ounces. Advertising campaigns and endorsement contracts secured the shoe companies global recognition for their brands and billions of dollars in revenues, while outsourcing to factories in low-wage locations kept production costs in check. To achieve all this required shoe companies to secure specialized expertise that once had no place even in "industrialized" shoemaking: of bio and software engineers, material technologists and scientists, and artists (to design new shoes); of lawyers to negotiate endorsement contracts with sports agents; of advertising agencies to produce commercials and purchase TV spots; and, of supply chain professionals to manage outsourcing.

New organizations have helped specialize and broaden innovation. Over the first half of the 20th century, 19th century inventions such as automobiles moved from workshops (of pioneers like the Duryea brothers) to functionally organized, founder-controlled concerns (such as Ford Motor) to professionally managed multi-

* Venturesome consumption has not widened uniformly. As I have argued (Bhidé 2016) long-standing traditions and contemporary rules have held back medical advances by limiting the role of consumers.

divisional corporations (such as General Motors). The new organizations didn't simply house low-cost, high volume manufacturing; they combined the contributions of many specialists -- in industrial engineering, design, financial analysis, marketing, and logistics, for instance -- to give consumers ever new yet affordable products. In medicine, diverse teams (including researchers, clinicians, engineers, technicians and publicists) employed by new multi-specialty practices (such as the Mayo Clinic and the Cleveland Clinic) played pivotal roles in the development and dissemination of treatments such as cardiac surgery. New kinds of professional firms employing diverse specialists (such as Arthur D. Little and McKinsey & Company) advanced new technical and managerial ideas. And mass discounters (such as Wal-Mart), multinational advertising agencies (such as McCann Erickson), and now e-tailers (such as Amazon) whet and fed appetites for venturesome consumption.

Mavericks continue to flourish, however. Spontaneous self-ordering did not create the Mayo Clinic and Wal-Mart, and entrepreneurs like Jeff Bezos have continued to shape the development of behemoths like Amazon. Audacious medical researchers continue to lead transformational advances in immuno-therapies. But maverick visionaries do not act alone – they play in a broader, multiplayer game. The immunotherapy pioneer Michel Sadelain found a home at Memorial Sloan-Kettering and private funding kept immunotherapy going when the mainstream consensus blocked government grants. New kinds of financiers that specialize in backing unconventional ideas, such as professionally managed venture-capital partnerships and informal networks of angel investors, have increase the potency of high-tech entrepreneurs. The upstart Apple of the 1970s and 1980s relied on semiconductors developed by large chipmakers. Now, developers of mobile phone apps depend on the app-stores and infrastructure that today's behemoths, Apple, and Google, maintain.

Problems, Antidotes and Tangles

Massively multiplayer innovation also poses problems. For instance, widespread venturesome consumption supports extensive specialization of development and high-volume production; but it also increases the difficulties of identifying and satisfying buyers' wants. Developers cannot easily anticipate what combination of features will best attract dispersed customers. In earlier preindustrial times, where artisans customized products for patrons the tasks of aiming (specifying features) and communication (between artisan and patron) was easier. Even Edison who did not customize products but targeted a niche of wealthy patrons faced less difficulty.

Similarly, global supply chains make products affordable but are harder to coordinate than low- volume production within a self-contained workshop: a geographically dispersed, multilingual workforce makes communication more difficult, precisely codified schedules and targets more necessary, and careful assignment of managerial responsibilities and authority crucial.

Many hands don't always lighten development work and too many cooks can even spoil the broth. As Frederick Brooks wrote in his celebrated book on software development, "The Mythical Man-Month: Essays on Software Engineering": "When a task cannot be partitioned because of sequential constraints, the application of more effort has no effect on the schedule. The bearing of a child takes nine months, no matter how many women are assigned." In fact, 'Brooks's Law' suggests that increasing the size of software teams may even delay development. Likewise, conflicts within multi-disciplinary teams can produce deadlocks and clumsy compromises – the proverbial camel crafted by a committee formed to design a horse.

These problems have spurred the development of techniques to support multiplayer innovation. Market research and advertising techniques can help innovators design and market products for mass venturesome consumption. Nineteenth century inventors like Thomas Edison designed and sold expensive novelties in a more improvised way. Similarly, contemporary organizations have routinized processes to make the diverse expertise of 'many heads better than one'.

But deliberate routines are typically slower than hunches, informal consultations, or unspoken convention and can suppress the foundational spirit of innovation. Ritualized market research can discourage venturesome leaps and by-the-numbers evaluations of new product sales can prevent organizations from persisting with visionary initiatives. And, as the tangle of techniques increases, so can their ineffective and deadening use.

A comprehensive Wikipedia won't lead us through the tangle. Nor can we expect a rigorous technique to choose techniques. Rather, we need a simple guide (or "walking stick" [11]).

Analytical Framework

Categorizing and Analyzing Tasks

My simplifying framework analyzes eight kinds of tasks encountered by developers of artifacts (and that, as was shown in Table 1, numerous techniques help them perform).

Six tasks (goal and problem specification, conjecture, evaluation and testing, codification, communication, and strategic commitment) are 'primordial:' they feature in any purposeful development of artifacts, as suggested in the first section of this Note.[12] The other two tasks (assignment of responsibility and authority and incentivization) are crucial mainly for organizing multiplayer development.[13]

Analysis of each kind of task asks questions about:

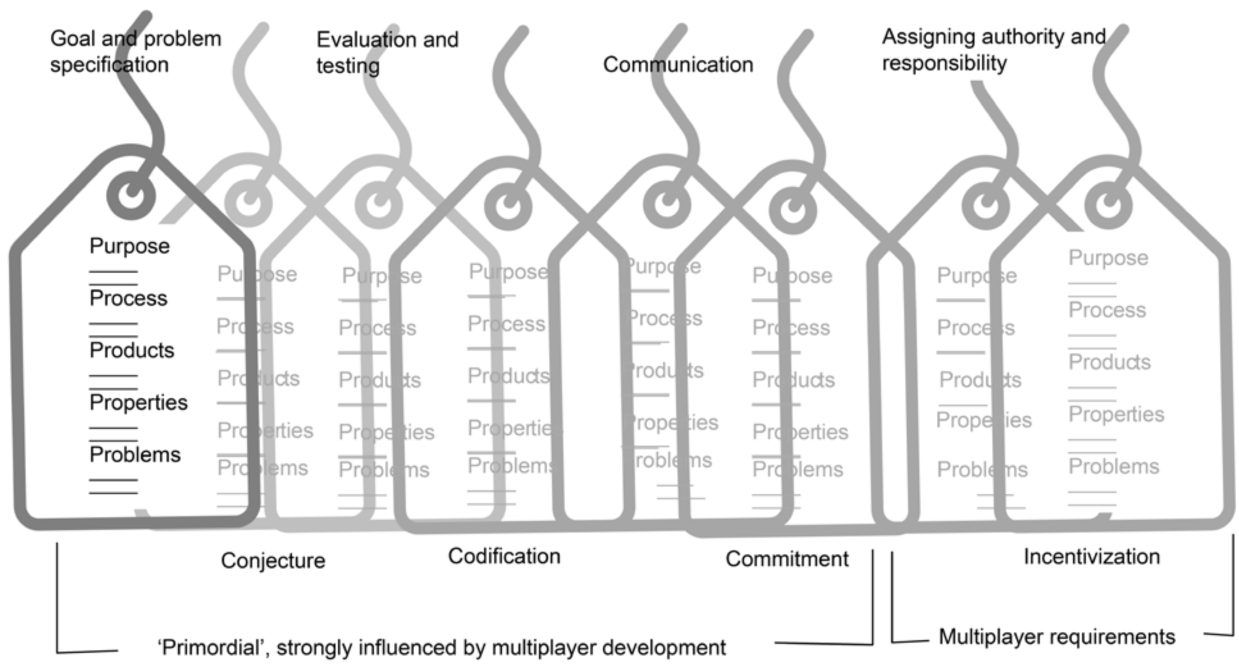
- *Purposes* -- the "whys" of performing the task. Tasks of the same general kind can serve different purposes; and even a single task can serve several explicit and implicit purposes.
- *Processes* – "how" the task is performed. Besides systematic techniques, the "how" can include alternatives such as improvisation and tacit conventions.
- *Products* – or "artifacts" resulting from performing the task. Here too, several kinds of products can be created by performing the same kind of task.
- *Properties* -- the "attributes" of what's produced along dimensions such as novelty, audacity, complexity and transparency.
- *Problems* – what might stop achieving the intended purpose(s).

The framework reflects my judgment about tasks of multiplayer innovation encountered in the widest possible range of domains, from health care, to electronics, to public services. Unlike groupings of elements in a periodic table the categories do not reflect any natural or physical divisions. Also, unlike groupings in the periodic table, the tasks overlap and crisscross. For instance, goal setting can intersect with testing and evaluation and with codification. If goals are precisely codified, they can serve as metrics for testing and evaluation. Similarly, communication often requires codification.

Many techniques also span multiple tasks. For instance, Human Centered Design protocols are intended to help specify goals for new products, develop creative conjectures for how these goals might be met, and rapidly test these conjectures.

The framework thus cannot provide a "mutually exclusive and collectively exhaustive" taxonomy. Rather, its tasks and their features are like 'tags' or 'keywords' (See Figure 2) not folders and filing cabinets: Whereas we can put a document in just one folder and that folder in just one cabinet, we can apply several tags and keywords to the same document.

Figure 2: Analyzing Common Multiplayer Tasks



Using the Framework

Cataloging Knowledge. The framework provides a template for cataloging knowledge in the same way that generic outlines can help National Geographic produce new guides and maps. The suggested categories of tasks can help divide the catalog into sections. Similarly, features of the tasks (such as their potential purposes and processes) can help organize the contents of sections.

Diagnosing Problems. Like a guide map, the framework can help address "are we on the right track" and "what problems lie ahead" questions. Such assessments might include asking whether the different tasks are being performed in a consistent way, are congruent with external circumstances, and are likely to produce the outcomes desired. The framework can similarly help diagnose misalignments within tasks. For example, analysis may show that a capricious or inflexible process may be undermining the motivational purpose of goal setting.

The need for judgment however remains. As shown in Figure 3 many purposes, processes, products, properties, and problems can characterize goal and problem specification tasks. The possibilities for misalignments are therefore vast and some are better tolerated than treated. For instance, while mechanically codified targets can make large organizations inflexible, new businesses can implode if they don't systematize goal setting. In other words, finding an apparent misalignment should prompt the question of "what's really going on here' – and why – rather than immediate changes.

Looking Outside. The rapid growth of knowledge creates a gap between what's 'out there' and what individuals and organizations use or even know about. Mature organizations that become set in their ways are particularly likely to fall behind. New organizations start with a clean slate and have the incentive to pick the best techniques they can afford. But success produces complacency and complexity that makes change difficult. Recruiting entry-level employees who have just graduated from schools and colleges – whose curricula also often lag -- and promoting from within reinforces insularity. And many new techniques (such as Human Centered Design) cross standard organizational boxes. No one therefore has the responsibility or authority to learn or apply the new knowledge.

A review of how organizations undertake the broadly defined tasks of my framework can alert them to gaps and blind spots. Moreover, because the framework focuses on widely undertaken tasks, it permits looking for methods from far and wide.

Figure 3: Analyzing Goal and Problem Specification

Products
- Mission or Value Statements
- Design Requirements and Targets
- Medical "endpoints"
- Budgets, Milestones and Quotas
- Contracts and agreements

Process
- Distilled from emergent practice
- Edicts of founders or leaders based on
  - Role models/values
  - Prior experiences
- Systematized Multiplayer Techniques
  - New Product and Strategic Planning
  - SLA template
  - HCD (Journey Maps)
  - OKR/MBO cascades

Purpose
- Motivate
- Stimulate search
- Criteria (for search + evaluation)
- Horizontal, vertical and temporal alignment
- Delegate and outsource

Problems
- Internal incongruence
- Mismatch with local circumstances
- Comprehensibility/Communication
- Attainability/Acceptability
- Unintended (adverse) consequences

Properties
- Ambition and audacity
- Level, scope and time horizon
- Direct, Surrogate or Oblique
- Comparative or absolute
- Complexity and transparency
  - Precision and completeness
  - Univariate, Indexed or Multivariate
  - Priorities/substitutions (if multivariate)
  - Horizontal variations and local discretion
  - Negotiability/strict enforcement
- Substitutes and complements
  - Tacit norms and routines
  - Reports and Dashboards
  - Conjectures
  - Rewards and Penalties

The figure illustrates the many purposes, processes, products, properties, and problems that characterize goal and problem specification tasks.

Bringing it in. Copying even simple artifacts requires knowing what to replicate. The proverbial wheel invented circa 3,500 B.C, needed axles with smooth and round ends that fit snugly into wheel holes – while leaving room for the wheels to rotate. The insides of wheel holes also had to be smooth and round. Wheels could not be replicated therefore just by seeing a cart roll by. Similarly, reusing complex multiplayer practices requires selective imitation and careful adaptation. (see Box 'Modernizing Japan').

Modernizing Japan

After extended isolation that led to humiliating military defeats in the mid-19th century, Japanese officials made an all-out effort to learn from the West. In 1872, the Iwakura Mission traveled around the world, touring factories, and studying legal systems and social customs. French experts were hired to help draft a new legal code, British experts provided advice on industry, and Americans on agriculture and education. Prussia provided a model for the army. Diplomats started to dress in coat and tails instead of kimonos, the Emperor could be seen wearing military uniforms, and the Empress in Victorian gowns. But the Westernization wasn't blind. Unlike Turkey after Ataturk, Japan did not adopt the Roman script. A new "*bunmei kaika*" ("civilization and enlightenment") policy did not grant Japanese women the personal freedoms that members of the Iwakura Mission had been surprised to find women enjoyed in the United States.[14] And, a new wardrobe did not alter the Emperor's divine status.

My framework provides a starting point for choosing what to copy exactly as well as what to adapt and how. Similarly, as we will see next, learning from case-histories of exemplary artifacts requires filtering and organizing the facts. Our analytical framework can help us do this.

Case Histories of Transformational Artifacts

Case histories can complement studying techniques in several ways. For instance, the heuristic of what Peters and Waterman (1982) called "loose-tight" controls can guide organizations seeking a middle ground between comprehensive top-down planning and uncoordinated individual initiative. Studying specific cases can help us learn what warrants tighter or looser oversight and control even if the cases themselves do not make this explicit. Similarly, cases can also get us to think about "sweet spots" for the applicability of techniques.

How studying specific cases improves the utility of general principles and vice versa is comparable to the symbiotic benefits of studying great novels as well as writing conventions. Aspiring writers may learn more about plot and character development from great novels than from studying the conventions of writing; but, knowing the conventions increases what aspiring writers learn by guiding their attention to how a great novel develops plot and character or deviates from standard techniques.

Studying specific cases also helps adaption and cross-fertilization of exemplary systems and architectures. As mentioned, well-designed artifacts embody many choices. But it is impossible for anyone to anticipate the right constellation of choices from a nearly infinite number of possible combinations. Rather, pioneering developers make a guess about their initial designs and about their subsequent modifications. These can take decades. Studying the architecture of artifacts facilitates adaptation and replication of the hard-won advances: Knowing *how* the elements of a complex artifact work together and align with exogenous circumstances provides useful hints about what might need to be changed.

The histories of transformational advances can tell us even more about their why's and wherefores. For example, Marvin Bower, who founded McKinsey & Co. and practically invented management consulting, used prestigious law firms and the legal profession as his base model. But Bower did not copy blindly. Rather he took what he expected would fit and invented the rest. With experience, Bower and his partners then gradually modified their model. Studying how the McKinsey system evolved in its first decades can provide insights about the logic of its basic architecture (which is not entirely self-evident today) and its applicability to other domains.

Finally, case histories can show the vital contributions of individual ingenuity, persuasiveness, occasional ruthlessness, and fortitude. Transformational advances require broad based movements with visionary leadership. Success may bring great financial rewards, exhilaration and possibly a place in history, but innovators also risk ruinous loss, frustration, and obscurity. To take such a perilous path requires courage and a love for adventure that case histories can stimulate and strengthen.

Appendix: Scientific Knowledge vs Techniques for Developing Artifacts

Interdependencies and Similarities

Scientific discoveries often play an important role in the development of artifacts. Thus, the discovery of nuclear magnetic resonance prompted the development of industrial spectroscopes used to analyze the composition of chemicals. In some instances, scientific understanding that came after the development of artifacts has helped improve the artifacts: thermodynamics improved the efficiency of steam engines, for instance.[15] Bacteriology and virology have improved the development of vaccines (which Jenner had pioneered in Britain before scientists had shown how bacteria and viruses cause disease). And practical problems can prompt scientific research that helps solve the problems. (Famously Pasteur identified microorganisms responsible for fermentation after brewers had asked him for help in limiting spoilage. Stokes therefore calls scientific research directed to a practical end, "Pasteur's Quadrant" research.)[16]

Conversely, new artifacts can advance scientific understanding. Recounting Henderson's quip that "until 1850, the steam engine did more for science than science did for the steam engine" physicist Malcolm Longair writes that James Watt's 1765 invention of a condenser, made in the course of repairing a steam engine, "led to the underpinning of the whole of thermodynamics."[17] Similarly the invention of electron microscopes brought to scientists' attention naturally occurring phenomena they could not otherwise observe and new instruments such as spectrometers enabled the testing of scientific theories. And going back much further to the Enlightenment, clocks produced for human needs helped inspire scientific efforts to debunk animistic theories (that for instance gave stones the 'will' to fall).[18] And, the development of telescopes provided the basis of Galileo's, and later Newton's revolutionary theories of planetary motion.

Similar human qualities and values drive both scientific research and the development of artifacts. Unlike biological evolution, both are propelled by purposeful human striving and creativity, and not just by chance. Both seek to learn from mistakes and extend prior successes. Both can require persistence – the discovery of the structure of DNA and of evidence of the existence of Higgs boson ("God") particles no less than the 19th century dream of controlled, fixed-wing flight. And both value observable phenomena (although in some scientific fields, observations can lag far behind theories).

Both combine increasingly dispersed contributions. Enlightenment science, like practical methods for making clocks and building ships, pooled ideas from countries that periodically fought bloody wars in Europe. Today scientific research, like commerce and industry, draws on contributions from every continent. And like the massively multi-player development of artifacts, globally dispersed scientific research requires aligning the goals, conjectures, tests, codification, and communication of scientists.

Obvious and Subtle Differences.

While science may spur the development of artifacts such as MRIs, improve steam engines, and help brewers, it cannot provide all—or even the greater part—of the knowledge that artifacts embody. This is an intrinsic feature of scientific knowledge, not a defect. In his seminal *The Scope and Method of Political Economy* (1890) John Neville Keynes (father of John Maynard) argued against confusing the science of economics from value-laden concerns about economic ends. Keynes also distinguished economic science from systematic techniques for attaining desired ends. Arguably, the distinctions help produce more and better science: if you want to find the glacial headstreams of a river stay away from the tributaries in the plains.

But, as mentioned in the main text and shown in Figure 1, the knowledge required to develop artifacts includes values and norms, systematic techniques, and tacit and contextual knowledge. To rephrase Schumpeter: apply as much electromagnetic theory as you please, you will never get a maglev train thereby. Similarly, the social sciences may offer general directions and signposts but cannot by themselves supply the organizational techniques that undergird multiplayer innovation. Just applying cutting edge economics, sociology, or psychology could not have produced Intel's goal setting system.

Moreover, scientific principles and methods have a distinct character and cannot serve as reliable models for these other kinds of knowledge.

Science is self-evidently different from tacit knowledge and knowledge of specific contextual facts, although scientists often use tacit knowledge and specific facts to perform experiments and producing hypotheses. Similarly, scientists themselves often emphasize the distinctions between objective scientific propositions and value-laden choices of ends which fall outside the scope of "positive" scientific research (as mentioned in the main text).[*]

The differences between science and systematic techniques are more subtle, particularly in fields such as engineering that draw heavily from scientific propositions. Yet, as Stanford engineering professor Walter Vincenti observes in *What Engineers Know,* "technology, though it may apply science, is not the same as or entirely applied science." Rather, it is "an autonomous body of knowledge, identifiably different from the scientific knowledge with which it interacts." (See Box 'Walter Vincenti: What Engineers Know'). Or to make Vincenti's point more colorful, the Mona Lisa is more than applied paint, although Leonardo did apply paint to produce his masterpiece.

Walter Vincenti: What Engineers Know

"Modern engineers are seen as taking over their knowledge from scientists and, by some occasionally dramatic but probably intellectually uninteresting process, using this knowledge to fashion material artifacts. From this point of view, studying the epistemology of science should automatically subsume the knowledge content of engineering. Engineers know from experience that this view is untrue… my career as a research engineer and teacher has been spent producing and organizing knowledge that scientists for the most part do not address."[19]

Science has become increasingly important to engineering since Vicenti's landmark book was published nearly 30 years ago. And conversely the use of increasingly sophisticated instruments has increased the reliance of scientists on engineering. Nonetheless, important differences remain between engineering and scientific knowledge – and between other kinds of systematic technical knowledge (of fields such as medicine) and the science they use. How the knowledge is produced – how scientific communities and developers of systematic techniques set goals, form conjectures, codify and communicate results and so on – is also different. In fact, the increased dispersion and specialization of both scientific research and technical development may have widened the gap, as we will see.

Internal Consumption and Production

Crucially, modern scientific communities are highly self-contained and autonomous: they produce knowledge mainly for internal use. Scientific knowledge may also have value in artifacts used by non-scientists, but that is not a necessary purpose. For many decades, the existence of the Higgs field was regarded as the central problem in particle physics although this had no obvious practical consequence.

Even scientific research in "Pasteur's quadrant" that is prompted by practical problems is generally insulated from the development of artifacts based on the research. The hunt for the pathogen causing AIDs had

[*] Economists and other researchers who seek to understand social phenomena in a scientific way may include norms and objective functions in their theories but primarily to better explain the consequences of people's normative choices or why people might make them. Like natural scientists, social scientists also exclude ethical inquiry about what people should want.

practical urgency: it would provide the basis for a diagnostic test. But the scientific hunt for the pathogen could be insulated from the design of test kits, whereas the design of the test kits had to consider practical issues of large-scale production, distribution, storage, usability, regulatory compliance and so on. And the "worth" of scientific results can transcend their direct utility. A scientific discovery that does not provide a direct or obvious way to solve the practical problem invoked to secure funding may nonetheless be celebrated as a valuable advance. Linus Pauling and his colleagues demonstrated in 1949 that sickle-cell disease occurs because of an abnormality in the hemoglobin molecule. Although the disease remains incurable, this discovery has been judged a milestone in the history of molecular biology.

And the specialized communities that produce – and are the main consumers of – scientific research themselves judge its worth. The communities specify questions that merit investigation, the range of hypotheses advanced, and the kind of reasoning and evidence they consider legitimate. Particle physicists established standards for the evidence that would establish the existence of the Higgs field. Fellow virologists evaluated the research produced by virologists at the Pasteur Institute in France and the National Cancer Institutes in the U.S. identifying a retrovirus now known as HIV-1 as the cause of AIDS. Even when scientists seek outside funding for scientific research that has an explicit practical end, funding agencies turn to the scientists' peers to evaluate the research proposal.

Internal use and evaluation significantly simplify coordinating scientific research. Even if the members of a community are geographically scattered, similar training and background makes them epistemically close. Scientists can therefore relatively easily anticipate what will appeal to 'buyers' and how to 'sell' their work. Even when scientists do their research to help develop an artifact (such as an HIV test) they usually don't need to learn the needs of end users. And, to the extent their research is self-contained, scientists don't have to coordinate with individuals and groups outside their community.

Internal evaluation also allows – although doesn't require -- scientific communities to privilege, as Thomas Kuhn termed it, "paradigmatic" ideas. Simply put, we can think of these ideas as the core assumptions that the members of a community take for granted and which bound the hypotheses they propose and test.[20] The paradigmatic ideas – in conjunction with the norm of citing and building on prior work – naturally align the research of competing individuals and groups who are also expected to make novel and creative contributions and facilitate the efficient communication of the results. And, as scientific communities become more globally dispersed, paradigms play a vital role in preventing fragmentation and balkanization.

(This is not to suggest that paradigms require scientists to eternally march along the same narrow path. As Kuhn pointed out, the accumulation of anomalies can precipitate a revolutionary collapse of paradigms. And scientists can drift away from the conjectures and questions framed by their community's paradigm. But, in either case, paradigms typically continue to align scientists' assumptions and hypotheses, either because a new paradigm follows a revolutionary collapse or scientists who drift away from the mainstream, branch out into a new community with a new paradigm that coexists rather than competes with the old.)

Paradigmatic Conjectures and Tests

Although the paradigms of different scientific communities encourage them to research different kinds of questions, they will generally tend to favor hypotheses (or what I have called "conjectures") that are:

• *Precisely, and preferably concisely, codified* —Newton's second law of motion, $F = ma$, and Einstein's law of mass-energy equivalence, $E = mc^2$ provide ideal examples.

• *Universal and timeless* — propositions are treated as scientific to the extent they abstract away from specific circumstances of place and time. Even in common usage, the more general a proposition, the more "scientific" it is regarded to be;[21]

• *Objectively verifiable* —through dispositive tests that satisfy fellow scientists.

Preferences for precise specification, universality, and verifiability, reinforce each other. For instance, scientists cannot verify imprecisely formulated hypotheses. Similarly, scientists tend to avoid events that occur in a particular time and place because many plausible but unverifiable 'just-so stories' can be told about the causes. And, like the specific paradigms of individual communities, the general preferences also promote cohesion and reduce the need for techniques to pool dispersed individual effort. For instance, precise specification and standardized verification allow scientists to communicate with each other efficiently and to rely on each other's work (without everyone replicating each other's results).

The degree to which different scientific communities require precise specification, universality, and objective verification varies (See Box 'Variations in Conjectures and Tests'). But even that aspiration, widespread in science, is not a common feature in practical knowledge development.

Variations in Scientific Conjectures and Tests

Not all scientific knowledge is concise – as anyone who has had to memorize the periodic table will testify – and cell biologists, ecologists, and zoologists treat detailed descriptions as contributions. But scientific communities that start with sprawling collections of facts strive for concise propositions. Science advances with "general statements of steadily increasing explanatory power" according to zoologist Peter Medawar, that "annihilate" the need to know particular facts. "Biology before Darwin was almost all facts," writes Medawar but now is "over the hump."[22] (Generality also seems to affect status. August Comte, considered the first modern philosopher of science, arranged the sciences "in the order of generality of the principles they establish[ed] (Knight 1921 p. 8). Molecular biologist James Watson who dismissed naturalist colleagues at Harvard who engaged in classification as "stamp collectors."[23])

Similarly, paleontologists do research and inconclusively argue about the one-off extinction of dinosaurs. But even in these instances, scientists reject evidence that lies in the eye of a particular beholder and they strive to develop more conclusive tests. As the evolutionary biologist Jonathan Losos puts it, for the first century of its existence, his field was thought to be similar to history: "You can't go back in time and see what happened, so you just have to try to figure it out." Now researchers "replay the tape" using microorganisms to test hypotheses in their laboratories.[24]

Standards for quality and membership

Scientific communities face strong incentives to strictly enforce their paradigmatic norms. While science may be highly "epistemically" self-sufficient, scientists require outside funding. But governments, foundations, and philanthropists who provide the funds cannot, as mentioned, independently assess the quality of the research. Rather, the outside funding agencies rely on certification provided by journals, whose referees and editors enforce rigorous adherence to the research community's standards for parsimony, precision, and testing. Similarly, not tolerating mistakes also helps scientific communities and publications avoid externally damaging perceptions of favoritism. Therefore, if referees raise credible objections, scientific papers aren't accepted for publication (in the expectation that the problems will be addressed in later iterations.) And increased competition between communities for outside resources and standing has likely spurred a tightening of criteria for hypotheses and evidence and reduced the scope for deviant or idiosyncratic inquiry. It also increases the confidence within the community in each other's work without requiring any knowledge of individual producers, who as mentioned are now widely geographically dispersed.

Along with – and possibly because of – stricter criteria, scientific communities have increased qualifications for membership. Bodies such as the Royal Society once included well-born gentleman-scholars – and even the Delft tradesman, Antonie van Leeuwenhoek, now considered the Father of Microbiology. But today, individuals who do not have PhDs and jobs at universities or recognized research institutions have been almost completely marginalized. Concurrently, the number of research communities, and the compartmentalized specialization of its members, has also grown. Thus, while the broadening of opportunities for higher education and the public funding of scientific research has made entering scientific communities more meritocratic and open to the not so-well-born, credentialed specialization has limited membership of specialized communities to individuals who have very similar knowledge, training, and career-experiences.

Requirements and Techniques for Artifacts

Outside Evaluation. In contrast to research that scientists themselves evaluate, outside users have a crucial role in assessing artifacts, and thus implicitly the knowledge they embody. Visionaries may develop products far ahead of anyone's articulated wants, but ultimately their success requires buyers to open their wallets. This does not mean that users always know what's good for them – patients continued to demand bloodletting from their sometimes-reluctant physicians through the mid-18th century and even today patients will ask for tests and treatments that doctors discourage. Moreover, the preferences of outside buyers are less predictable than the internal paradigmatic preferences of scientific communities. Except for customized goods such as kitchen cabinets buyers won't say what they want yet their wants are often inchoate and fickle. Today's venturesome consumers are not merely willing to take their chances on novelties, they often demand surprising features or combinations of features.

Incomplete Codification and Contextual Dependencies. Developers, producers, and users of artifacts cannot rely just on parsimonious, precisely specified knowledge. As mentioned, knowledge embodied in artifacts comprises a complex tangle. Some of this knowledge is indeed precisely specified – in engineering drawings, circuit diagrams, and project plans for instance. But knowledge used to develop, produce, and use artifacts also inevitably has tacit complements. And precise specification can be expensive or even harmful. For instance, it may be cheaper to let employees learn by doing, and more effective to allow them to adapt to changing circumstances, than to precisely specify (a la Henry Ford) how they should perform assigned tasks.

Generalizability across uses and time has similar tradeoffs. All airplanes must be designed to conform to universal laws of nature; but there is value to adapting designs to intended use (e.g. long-haul versus short-hop, or cargo versus passenger). Moreover, given the practical difficulty of getting something to work, developers will often first tune their artifacts for specific circumstances and for specific users and then look for ways to generalize their designs for broader applications.

Artifacts also must match changes in tastes and the Zeitgeist. Unlike scientists who seek to discover the unchanging laws of nature, developers of artifacts cannot produce timeless designs. And, besides changing tastes, increasing use itself can affect utility. For instance, the capacity of standardized credit scoring to predict loan defaults deteriorated when its increased use by lenders taught borrowers how to game their scores. Conversely, learning or network effects can increase utility. For instance, the popularity of a surgical technique can accelerate its improvement, and wide adoption of a programming language such as Java can make it a valuable standard. In contrast, increased acceptance of a scientific hypothesis does not affect its correspondence to nature: whatever reality is "out there" remains unchanged.

Flexibility of Standards. Developers of many artifacts face less rigorous standards than those imposed by gatekeepers of scientific research because users consider mainly their own costs and benefits (rather than enforce a group norm). Thus, unlike referees of journal articles, users of new artifacts are often willing to tolerate obvious limitations in the expectation that they will be fixed. In some cases, the expectation can even lead to acquisitions of buggy "first generation" products that make users temporarily worse off.[25]

Membership criteria for joining the multiplayer innovation game are also more flexible than the criteria now imposed by scientific communities. The increased division and specialization of labor in the development and use of artifacts has, as in the sciences, raised standards for the qualifications required of many specialists. However, there are important differences. Artifact development has continued to provide entrepreneurial opportunities for college dropouts like Bill Gates, Steve Jobs, and Mark Zuckerberg (who would now be excluded from scientific communities), and the companies they have founded (Microsoft, Apple, and Facebook) recruit many self-taught hackers. Moxie Marlinspike, whose encryption programs have been embedded in applications used by billions, barely finished high school before finding a job in Silicon Valley. Moreover, the wide inclusivity isn't the result of more fair-mindedness or impartiality. Rather, global competition to satisfy ever more demanding consumers requires integrating the efforts of a wider range of talents and skills than producing scientific research for specialized communities.

Systematic Techniques. Outside evaluation (and the other distinctive features of practical knowledge development) have stimulated the development of techniques (discussed earlier in this overview) that are not widely used by contemporary scientific communities. For example:

• Anticipating 'outside' users' often inchoate wants (rather than predicting what like-minded scientific colleagues will value) has spurred conjoint analysis, focus group, and 'design thinking' techniques. Similarly, while scientists continue to rely mainly on traditional journal articles and conferences to disseminate their findings, developers of artifacts use a plethora of new communication techniques such as You-tube videos, tweets, podcasts, and pop-up stores to inform and persuade buyers.

• Evaluating complex artifacts that must satisfy several performance, safety, legal, and societal requirements has spurred computer simulations, rapid prototyping, A/B testing, field observations and other such techniques. Unlike experiments undertaken to satisfy scientific colleagues (and journal referees) these techniques aren't designed to produce dispositive validation of a parsimonious hypothesis; rather the techniques seek to incorporate all the external factors likely to affect the performance of artifacts under conditions in which the artifacts will be used, rather than "control" for these factors.

• Efforts to coordinate diverse tasks performed by widely dispersed individuals with different predispositions and training (rather than by communities of like-minded scientists) has spurred new techniques for setting goals, motivating employees, structuring organizations, and managing projects that cross organizational boundaries.

Concluding Comments

Like Vincenti, Henry Petroski, Professor of Engineering and Professor of History at Duke University has emphasized the difference between technology and science in numerous books and articles. In the first paragraph of *The Essential Engineer* Petroski writes that "both medicine and engineering do use scientific knowledge and methods to solve relevant problems, but neither is simply an applied science. In fact, the practices of medicine and engineering are more like each other than either is like unqualified science." Yet, Petroski continues, "the word science is commonly understood to include medicine, engineering, and high-technology.[26]

Petroski offers a convenient distinction: "*science is the study of what is; engineering is the creation of what never was.*" But confusion arises because "even in their most basic professional activity, scientists can act like engineers (and vice versa)… Chemists regularly synthesize new compounds, and biologists create new strains of plants and animals that do not exist in nature. In other words, scientists can do engineering (as engineers can do science)."[27]

And while "Science" is a "useful shorthand for a wide range of activities" Petroski complains that the expansive label also "obscures differences" and gives science "a primacy that it may or may not deserve." Petroski cites several examples, going back to the 1950s, of newspapers attributing engineering successes to "science" and "scientists" – while attributing failures to "engineering" or "engineers." This bias could reflect educational backgrounds; nearly all science reporters study science not engineering in college Petroski observes. Or it might come from a "Western Platonic bias" that views "scientists who deal in ideas, even ideas about things… as superior to engineers who deal directly in things."[28]

The lower standing "provides fodder for engineers who feel that their profession is misunderstood and undervalued." Some see a reflection of the "hierarchical structure between the sciences and engineering" at prestigious research institutions in inaccurate media accounts rather than "just innocent confusion or carelessness."[29] But, whatever the cause, confusing science and engineering "can leave politicians, policymakers, and the general public unable to make informed decisions" including decisions about the allocation of research funds. (Petroski argues for funding more engineering projects) [30]

This seminar distinguishes between science and systematic knowledge in domains beyond engineering. As in this appendix, we emphasize how practical methods reflect practical goals (of helping create things rather than increasing our understanding of how the world already is). And, in some of our readings we review the errors of omission and commission produced by the unwarranted imposition of scientific sensibilities and methods[31]. As we will see, there is more at stake than status and semantics or even the division of resources allocated to scientists and technologists.

Notes

[1] An inflexible adherence to methods demanded by scientific communities can therefore hinder the development of artifacts. Rather, effective development requires an eclectic choice of techniques – and the willingness to deviate from standards required for peer-reviewed scientific publication.

[2] We often accept or reject options just in our minds. We don't expose every possibility that we might think of to a competitive battle for survival outside our imaginations and even our external evaluations reflect our choices of test designs and interpretation of the results.

[3] As the Chicago economist Frank Knight wrote in *Risk, Uncertainty and Profit* (1921)

[4] *Contra* Schumpeter's "gales of creative destruction" imagery however, the alternative technologies can take decades to gather force.

[5] And possibly the existential anxiety that Kierkegaard said attends such leaps.

[6] According to Dewey, even the most thorough and careful inquiry could at best produce "warrantable assertions" – provisional, more-or-less reliable claims, supported by a reasonable warrant.

[7] John Dewey devoted his life to radically reforming education, while James suggested unusual measures to increase one's productive working hours by curtailing sleep. Later 20th century "neo-pragmatist" philosopher Richard Rorty promoted *Social Hope* (for a "global, cosmopolitan, egalitarian, classless, casteless society" as he put it in the preface).

[8] Rosenberg (1976) p.75-76

[9] Usselman (1992) p. 254

[10] https://runningtortoiseandhare.wordpress.com/running-shoes/history-of-running-shoes/

[11] To borrow a term from Roethlisberger (1977)

[12] Massively multiplayer innovation has however significantly influenced these tasks, as suggested in the section directly above.

[13] The managerial tasks play an especially important role in initiatives undertaken by large hierarchies (such FAANG and large pharma companies) and networks (such as the National Institutes of Health and 'open system' software developers).

[14] Ethan Segal, "Meiji and Taishō Japan: An Introductory Essay" downloaded on August 26 2018 from https://www.colorado.edu/cas/tea/becoming-modern/1-meiji.html

[15] Scientific knowledge can also help control dysfunctional practices – for instance, ignorance that Vitamin C rather than all sour tasting substances prevent scurvy is said to have led to its resurgence when the British Navy substituted lime juice for lemon juice in sailor's diets (Barron 2009).

[16] Stokes, Donald E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation.* Washington, D.C.: The Brookings Institution

[17] Longair, Malcolm S. 2003. P. 223. *Theoretical Concepts in Physics: An Alternative View of Theoretical Reasoning in Physics.* Cambridge: Cambridge University Press

[18] Shapin p xxx

[19] Vincenti (1993) p. 3 W.G. *What Engineers Know and How They Know It*, Baltimore: John Hopkins University Press,

[20] Scholarly communities in the humanities who have as much autonomy as scientific communities to choose their norms have apparently not favored internal paradigmatic consensus. This may derive from a tradition of contention that preceded the Scientific Revolution. In the sciences, the founding figures, Shapin's account suggests, explicitly rejected norms of irreconcilable contention.

[21] For instance, Hayek (1945) contrasts scientific knowledge of "general rules" with "knowledge of the particular circumstances of time and place."

[22] Medawar (1982 p. 29)

[23] Watson may have borrowed his putdown from the physicist Ernest Rutherford who supposedly once said: All science is either physics or stamp collecting. Petroski 2010. p. 33

[24] Interview with Losos published in Harvard Gazette downloaded from From <https://news.harvard.edu/gazette/story/2017/10/evolution-book/?utm_source=SilverpopMailing&utm_medium=email&utm_campaign=10.03.2017%20(1)>

[25] Users' tolerance for imperfections in artifacts isn't blind however and depends on first hand examination of the artifact and the reputation and persuasiveness of individual producer.

[26] Petroski 2010. p. ix

[27] Petroski 2010. p. 21

[28] Petroski 2010. p. 24

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[29] Petroski 2010. p. 26

[30] Engineering Is Not Science - IEEE Spectrum. Downloaded from https://spectrum.ieee.org/at-work/tech-careers/engineering-is-not-science

[31] Examples include basing macro-economic policies on context-free deductive models or requiring dispositive, controlled testing of innovative medical treatments