Syllabus

Seminar on Practical Knowledge: Sustaining Massively-Multiplayer Innovation

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Governments and universities are pouring money into more ‘practical’ research – ‘translational’ medicine and ‘evidence-based’ policies in education, public health and economic development, for instance. But just translating or applying science rarely produces practical advances – and an inflexible adherence to the methods of natural or social scientists can do more harm than good. Instead, I propose a general approach – and specific research topics – to advance practical knowledge and study its distinctive contemporary nature. My proposal is implicit in this syllabus (of a seminar I have been teaching since 2013.)

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Table of Contents

Overview

This seminar examines the development of knowledge embodied in artifacts (including physical objects, protocols, and organizations) intended to transform "existing conditions into preferred ones."[1] We are particularly interested in knowledge that is developed by and for the many. Thus, we care more about how ready-to-wear footwear is designed, produced, and sold, than in customizing handcrafted boots for buyers who don't think about the price. Likewise, general tools and techniques are of greater interest than specialized tools. Thus, we are interested in how consumer goods, not just shoes, are designed, produced, and marketed.

By traditional and modern intellectual standards, studying practical knowledge may seem undignified. The ancient Greeks venerated contemplation, music and the other arts, abstract truths, and mathematical reasoning. Merchants and craftsmen (including, presumably, builders of large hollow horses) occupied the bottom rung of Plato's idealized society; their knowledge and toil was but a means towards the realization of the good life by 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 or simply unfounded superstition.

In higher education too practical knowledge lacks high status. The first European universities started by offering medical and legal training, but then emphasized theology and other contemplative subjects. In the US, the University of Pennsylvania emerged from Benjamin Franklin's 1749 proposal for an Academy to teach "those Things that are likely to be most useful."[2] The primary purpose of land-grant colleges created by the Morrill Act (signed into law by President Lincoln in 1862) was "to teach such branches of learning as are related to agriculture and the mechanic arts." But now, some in the upper ranks of the US as well as European professoriate, deride professional education as verging on the teaching of trades that must be kept in its subordinate place.

Yet, practical knowledge affirms an essence of our humanity. We are human because we create, not just because we think abstract thoughts. Beavers build dams, prairie dogs excavate underground towns, and crows craft toys. But, 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 knowledge created through the exercise of faculties that mark us as human: to imagine, to reason, to have faith and to control our anxieties, to communicate and collaborate, and to "truck, barter, and exchange" as Adam Smith put it. According to a recent book by evolutionary biologist, Joe Henrich, humans are not particularly physically impressive or even smart. Rather, our capacity for cooperation has made humans a uniquely successful species.[3]

Synthesizing complex techniques and tools to make useful artifacts is also uniquely human. At best, other species craft rudimentary implements by taking apart natural objects, such as twigs, whereas human civilization has been propelled by techniques and tools of increasing sophistication. Our cave dwelling ancestors, unlike their simian progenitors, learned to kindle fires. The Neolithic or the First Agricultural Revolution started relieving us from the vagaries of nomadic hunting about 10,000 years ago through inventions such as irrigation, selective breeding of cereal grasses, and harvester's sickles.

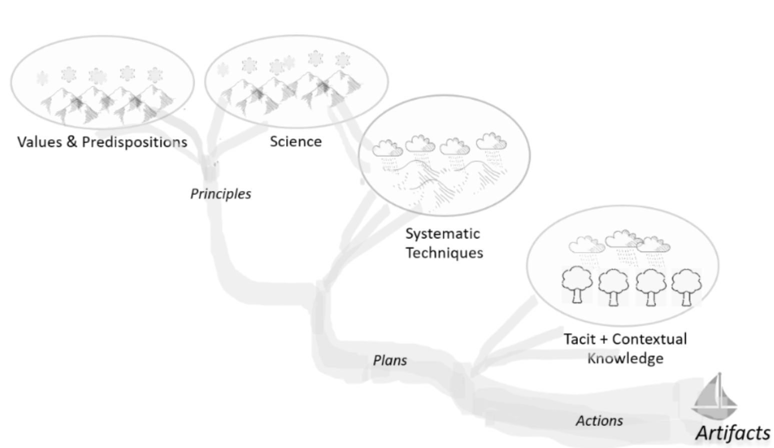
The Second Agricultural Revolution that started in Britain in the mid-17th century brought crop rotation, breeding of livestock, land drainage and reclamation, and plows that could be easily pulled and controlled. The Industrial Revolution that started after about 1760, mechanized textile production through power looms and cotton gins, increased the efficiency of steam engines 5 to 10-fold, and slashed the cost of producing iron by using coke instead of charcoal in larger blast furnaces. And, whereas mobile phones, tablets and laptops may be the more celebrated products of the Digital Revolution, specialized techniques and tools that many of us never see, such as computer-aided circuit design and numerically controlled semiconductor fabrication, have made the prominent consumer artifacts affordable and miraculously versatile.

Our capacity for collaborative practical 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. Before, the development of artifacts relied on exceptionally talented individuals. Similarly, where inventors once produced novelties principally for powerful or wealthy patrons, contemporary innovation relies on widespread consumption of affordable artifacts. And, the combination of widespread consumption and development has made innovations at least as consequential as novelties, such as telephones and automobiles, invented in the 19th century by and for the few.

Massively multiplayer development has itself been supported by new techniques and tools. These include protocols that help innovators choose goals and objectives, produce plausible conjectures for attaining these goals, evaluate and refine the conjectures, codify and communicate selected ideas, delegate tasks, and motivate and control contributors. The multiplayer game does not exclude unplanned discoveries and epiphanies. But, like farming after the agricultural revolutions, 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.

Scientific discoveries have provided a crucial starting point for many technologies — the transistor principle for producing semiconductors or genetics for high yielding crops. And the increased output of scientific discoveries has provided more starting points. But, technology doesn't just gush out of scientific geysers. Just as much of the water that a river carries into the ocean does not originate in headstreams, science does not provide all the important knowledge embodied in artifacts. The watersheds of practical knowledge (See Figure 1) include: values and norms, that along with science, provide the guiding principles; systematic techniques (drawn from the technical knowledge of engineering, medicine, management and other such purposeful fields) that help turn the principles into plans; and, the tacit and contextual knowledge that turns plans into actions that culminate in new artifacts. 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.

Figure 1: The Many Watersheds of Practical Knowledge



That scientific watersheds cannot by themselves provide all the knowledge embedded in artifacts is an intrinsic feature of science, 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 objective science of economics from value-laden ethical concerns about economic ends. Keynes also distinguished economic science from systematic techniques and precepts 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 the purposeful development of artifacts requires choices of ends and the application of techniques: if you want to support farming and shipping downstream you need to know more than where rivers originate. You need to choose value-laden goals for downstream pollution and flooding, treat sewage, build locks and dams, and prevent soil erosion and deforestation in the lower watersheds. (Figure 1 depicts some, not all, the sources of the knowledge artifacts embody.) And, many artifacts don't even originate in scientific watersheds. The "upstream" principle of rewarding repeat customers, used by the loyalty programs of airlines and hotels, isn't 'scientific' in any normal sense of the term for instance.

Moreover, effective ways of developing different kinds of practical knowledge are different. Methods designed for scientific discovery aren't always best for choosing "upstream" ends, developing systematic "midstream" knowhow, or acquiring tacit "downstream" knowledge. An inflexible adherence to methods demanded by specialized scientific communities can therefore hinder the development of artifacts.

Goals. We emphasize systematic techniques – the "mid-level" watershed in the diagram above; we will treat the normative and scientific watersheds "above" and the tacit knowledge watershed "below" mainly as complementary sources of knowledge. And, because even this mid-level watershed covers a forbiddingly vast territory, we will prioritize:

- Techniques that facilitate multiplayer development over techniques that individuals may want to learn for their personal improvement such as time management.[4]
- Techniques used to perform tasks commonly encountered in many domains (See Table 1) although some of the techniques themselves may be domain specific.
- The main features and tradeoffs of alternative techniques rather than deep mastery in practices that experts have deemed as "best."

Table 1: Common tasks and examples of techniques used to perform them

Tasks:	Examples of Techniques:
Goal and Problem Specification	Objective and Key Results; Journey Maps
Conjecture	Positive Deviance; Root Cause Analysis
Evaluation and Testing	Randomized Control Trials; Rapid Prototyping
Codification	Checklists; Best Practice Programs;
Communication	Pyramid Principle; Social Media Marketing
Commitment (to Strategic Goals and Policies)	SWOT, Five-Force Frameworks
Delegation	Organizational Templates; Project Management
Incentivization	Efficiency Wages; Job Enrichment

This classification of common tasks and examination of the techniques used to perform them is designed to provide the following kinds of benefits:

Creative Cross-fertilization. The adaptation of airline industry checklists to surgical operations provides a good example of learning about and applying practices across seemingly unrelated domains. The adoption of Toyota's lean-manufacturing techniques by hospitals and other service providers offers another example. There is ample scope for a lot more cross-fertilization – and this potential has guided my selection and categorization of tasks (as goal setting, conjecture, testing, etc.) that I believe arise in most practical domains.

Learning about problems encountered in other domains can also help practitioners avoid repeating mistakes. For instance, many experts (and I) believe that over-enthusiastic use of Randomized Controlled Trials (RCTs) in fields such as education and economic development has been a costly and avoidable error: awareness of the difficulties encountered in using RCTs to evaluate coronary bypass surgery during the 1970s and 1980s might have reduced its deification as a "gold standard" (rather than something which is sometimes useful and in limited ways).

RCTs also exemplify the misapplication of methods favored by scientific communities to the practical sphere. The mechanistic use of reductive models produced by economists – who assert a disciplinary claim to social science rather than a less structured study of social phenomena – also illustrates the consequences of scientific overreach. The seminar does not however encourage impulsive fast thinking. Rather it promotes the pragmatic selection of tools from a diverse catalog[*] – and the willingness to deviate from evidentiary and methodological standards needed to pass peer-review.

Assessing problems. Our examination can help distinguish problems that should be corrected from annoyances that are better tolerated than treated. The extensive codification and standardization that now pervades everyday life is one important example: we see how rigidly applied statistical models (e.g. in credit scoring) produce costly Type I and Type II errors and how more flexible methods allow the improvisation and decentralization that, as Hayek argued, sustains the dynamism of economies and organizations. We also find cases where standardized routines are a necessary evil, however and even cases where more codification might help: for instance, medical communities often produce "consensus guidelines" for treatments and tests. Yet producers of guidelines have no guidelines they can follow. Similarly, the bureaucratization of many large organizations is widely scorned. Yet, as we will see when we study "delegation" tasks, the "bureaucratic" routines of large organizations serve an important entrepreneurial purpose (as in the development of the iconic IBM 360). Eliminating the routines can also destabilize their on-going operations while many fast-growing businesses can spiral out of control if they don't implement and learn to tolerate large-company routines.

Discovering dangerous blind spots ("unknown unknowns"). Educational institutions can unknowingly leave dangerous gaps in their teaching and research. As Peter Burke and other historians have pointed out, the role of universities in transmitting 'canonical' knowledge discourages rapid changes in their research and in the courses they offer. Practical techniques (and other knowledge) developed outside universities during and after the Renaissance, Burke shows, ran ahead of university curricula. This lag created opportunities for "academies" founded in Sorø (1586), Tübingen (1589) and Madrid (1629) that taught "noble boys" "skills considered useful" for careers in the army or diplomacy.[5] More recently, in the 1980s, two enterprising physicians from Nashville, Tennessee and a device producing company (founded by a former salesman) led medical schools and teaching hospitals in the development and dissemination of laparoscopy.

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[*] The pragmatism necessary to effectively combine tools requires more than just forming multidisciplinary teams. Problems of accommodating the methodological norms of researchers from different fields can negate the advantages of pooling their knowledge. The striving of researchers for standing in their home disciplines can also undermine practical effectiveness. We include techniques for pooling diverse expertise in our examination of several tasks, most notably "delegation" and "incentivization."

Similarly, lags in computer science courses have required programmers to learn about current tools and techniques on the job, after they have graduated.

The relentless growth of knowledge produced outside universities (along with the commendable aversion of faculty to superficial instruction) continues to widen the gap between what's 'out there' and what's taught in classrooms. In fact, faculty often don't know about new techniques developed outside universities – or cannot easily fit them into traditional curricular boxes. At the same time, the less prestigious professional schools whose brands alone cannot justify their fees face the prospect of closure.

Falling behind can also endanger other organizations. New and fledgling businesses have the flexibility and incentive to pick the best techniques they can afford. They start with a clean slate and struggle against established rivals. But, once they make it, they can become set in their ways; increasing complexity makes change difficult and success dulls the drive to use or even learn about what is out there. A tendency to recruit entry-level employees who have just graduated from schools and colleges and promote from within reinforces insularity. Therefore, mature organizations who call themselves 'learning companies' often rely mainly on internal experience to develop new knowledge.

Our classification of tasks and examination of techniques can help organizations and their employees reduce the neglect of valuable current knowhow. The classification, which does not follow the divisions and preconceptions of organizational charts and academic curricula, can support open-minded stock-taking of what an organization knows and uses. And the techniques examined can help identify specific gaps.

Analytical aids cannot however produce or replace the venturesome drive needed to create artifacts. The seminar therefore targets hearts as well as minds. We aim to show that striving to satisfy others' wants is a noble adventure. Success may bring great material rewards, exhilaration and possibly a place in history, but innovators also face the possibility of ruinous loss, frustration and obscurity. To proceed on such a perilous path requires more than scientific, technical or tacit knowledge: it demands a love for adventure and the courage to continue when things go wrong. Thrift and bourgeois virtues of temperance and prudence celebrated by Max Weber and Deirdre McCloskey as the foundation of modern capitalism have their place — when joined to against-the-odds audacity.

To this end we celebrate the venturesome pragmatism of and for the many. Much has been written about the failings of contemporary societies and "technostructures" (as John Kenneth Galbraith called it). But if we disdain what we have secured, we risk losing it. Moreover, the overall benefits far exceed the sum of individual advances and material gains produced and we cannot reduce our social failings by suppressing our collaborative creativity.

Our mind-and-heart objectives limit the utility of studying well-codified "book" knowledge because many of the practices we are interested in have a fuzzy, tacit character. Yet, whereas we can often best acquire individual skills (such as making a sales call, or performing an appendectomy) through hands-on practice, this is less feasible in tasks performed by large, geographically dispersed groups. Even projects undertaken by student teams over the course of an academic term cannot replicate the exhilaration and distress, and the breakthroughs and stumbles, of protracted, multiplayer development. Similarly, studying concrete artifacts can help us reproduce them or use their key features in different domains. But we cannot directly examine many artifacts in an academic term or even a lifetime.

Therefore, we complement our review of tasks and techniques with detailed but not exhaustive case histories of noteworthy artifacts (including new technologies, products, protocols, and organizations). Like techniques, the artifacts can suggest possibilities for cross-fertilization while the stories of their evolution illustrate the dynamics of multiplayer development including the emotional challenges of doing something new. The case histories will also help produce, in a concrete bottoms-up way, a general appreciation of what multiplayer innovation delivers.

The next sections and a concluding appendix review the:

- Foundational requirements for developing and using artifacts
- Benefits and challenges of multiplayer advances
- Common tasks and techniques arising from multiplayer development
- Noteworthy artifacts whose evolution exemplifies multi-player development
- Contrasts between practical and scientific knowledge.

Foundational Requirements for Developing and Using Artifacts

Willful Advances

Genetically encoded biological evolution provides a useful contrast for illuminating 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 of ingredients, 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 – the development of 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 that produces transformational artifacts evolves through the extended accretion of changes, and not in a single bound.

But there is a crucial difference between biological evolution and the development of artifacts. Although artifacts do not spring full-blown from the mind of an omniscient creator, their extended development requires willful choices absent in biological evolution.

In nature, mutations occur randomly without any purpose or end. And, as the political scientist and philosopher Jon Elster notes, the subsequent process of selection occurs in a simple deterministic way — the evolutionary 'machine' accepts a mutation if it endows the first organism in which it occurs with a superior reproductive capacity. Natural selection thus 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."[6] 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.

The development of artifacts requires will, imagination and reason. We choose goals and the problems we wish to solve. We form and evaluate conjectures about how we might attain our goals and make willful choices about how to evaluate these conjectures. 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. And new ideas diffuse through deliberate efforts to codify, communicate, or imitate, not through the unconscious inheritance of mutations.

Strategic Persistence

Strategic choices and commitments play an important role in accretive development. Unlike natural selection, willful humans can dismiss seemingly favorable options – or even accept unfavorable options – "in order to gain access to even more favorable ones later on."[7] And, if we encounter unanticipated setbacks, we can examine what went wrong and adjust our course without changing our overall direction.

We can thus persist with general, strategic principles while adapting our more tactical choices through testing and learning from our conjectures.

The development of fixed-wing aircraft provides a striking example. Sir George Cayley first enunciated the underlying premise – 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."[8] 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, resourceful and courageous inventors had experimented with gliders, steam engines, gasoline engines, propellers, automobile chains, and rudders. One intrepid pioneer, 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

Developing artifacts require more than just cerebral calculation. Like myopic natural selection, forward-looking strategies, however thoughtfully formulated, can also lead to dead ends. 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 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, to borrow from economist Frank Knight, unmeasurable and unquantifiable risk. Skeptics who bet against new technologies – producers of buggy whips, oil lamps, and sailing schooners, for instance – can be swept away.[9]

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.'[10] 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.

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 have to 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 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 credo avers it is more important to ask what works rather than what is true. (And 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.)

Developers of practical knowledge are obviously more pragmatic in favoring the useful over the ultimately true. They also 'pragmatically' 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 have to 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. 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).

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.

Efforts to avoid this anxiety 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.

Benefits and Challenges of Contemporary Multiplayer Advances

A Transformational Widening

Multiplayer contributions give a contemporary shape to the foundational requirements discussed above. 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 couldn't 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."[11]

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. And, systematically harnessing the creativity and enterprise of the many has resulted in more, better, and affordable innovations.

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."[12] 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.

New organizations have played an invaluable complementary role. 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-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.

Traditional entrepreneurship continues to flourish, however. Nimble, audacious entrepreneurs continue to lead pathbreaking advances in new markets and technologies which require large leaps of faith. 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 their potency. But nimble visionaries do not act alone – they fit into a broader, multiplayer game. The upstart Apple of the 1970s and 1980s relied on microprocessors developed by large semiconductor companies. Now, developers of mobile phone apps depend on the app-stores and infrastructure that today's behemoths, Apple and Google, maintain.

In addition to enabling new artifacts such as smartphones and driverless cars, collaborative specialization has also transformed traditional manufacturing, as the case of running shoes shows. 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.[13] But these innovations did not launch multi-player development of running shoes for mass markets.

Eventually, 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 to consumers. 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. High-profile advertising

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

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.

Challenges

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 serving buyers’ wants. Developers cannot easily anticipate what combination of features will best attract dispersed customers and iteratively incorporate user feedback. Similarly, complex supply chains make products affordable but the risks of disturbing them discourage changes – including of the artifacts produced.

And, many hands don’t always lighten development work. 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 actually delay development. Likewise, many heads may be better than one, but too many cooks can spoil the broth. The collective effort of individuals with different expertise and perspectives can produce elegant solutions as well as 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. Innovators can now use market research and advertising techniques to design and market products for mass venturesome consumption. Nineteenth century inventors like Thomas Edison designed and sold expensive novelties in a more improvised way. But ritualized market research can also preclude venturesome leaps and by-the-numbers evaluations of new product sales can prevent organizations from persisting with visionary initiatives. Yet, the tangle of techniques is constantly increasing, as is their effective and deadening use.

Common Tasks and Techniques (Module I)

Evaluating all available techniques, that range from precise step-by-step procedures to general frameworks, is obviously beyond our scope. Instead, we will use the following classification of tasks commonly encountered in multiplayer development to survey some widely used techniques.

• *Goal and problem specification*. Any purposeful development requires choosing goals. Multiplayer development of artifacts for wide use significantly expands the range and complexity of goal specification. The overall value of an artifact as well as targets for its costs and technical attributes must be chosen to maximize its appeal to users who may have different tastes and preferences, for example. Similarly, goals and targets have to be established for the many functions involved in developing, producing, and marketing the artifact. In addition, multiplayer development is often undertaken by organizations that produce several artifacts and whose effectiveness depends on the quality of goals set at several levels: goals for the organization as a whole, for its subunits, and for its individual employees.

Although top-level goal setting has not been systematized, several techniques have been developed for setting lower-level goals (effectively “means” subordinate to the higher ends) or include such goal setting as an important part of the technique. For instance, Human Centered Design protocols use ethnographic procedures to choose target attributes for new products, and as mentioned, Intel's goal setting system establishes objectives for organizations and employees.

• *Conjecture* (generating ideas and hypotheses). Traditionally, the invention of new means was believed to result from an ineffable process of individual creativity which could not be systematized (although periodically individuals like John Stuart Mill would try). Now, organizations seek to harness the expertise of large teams using a variety of techniques to organize collective innovative effort, leaving less to unplanned epiphanies. These include, as already mentioned, assembly line style drug development; Human Centered Design protocols that seek to reduce cognitive barriers to creativity and the tendency of groups to avoid unconventional ideas; and, most recently, machine learning. At the same time, some experts and writers have sought to reemphasize the role of "intuitive" (rather than structured) problem solving.

• *Evaluation and Testing* can serve many purposes such as choosing the base technology of an artifact, modifying its features, and troubleshooting. Tests and evaluations may also serve to screen or grade the inputs used and outputs produced in the ongoing production of an artifact. For instance, a bank may want to screen job and loan applicants and control the completeness of loan and collateral documentation. The range of techniques used for these multifarious ends is also correspondingly wide and can include instruments such as balanced scorecards, learning assessments, randomized control trials, A/B testing, credit scoring, reference checks, and structured interviews.

• *Codification*. Precisely codified ends (and means for their achievement) are less likely to be misunderstood when transmitted across organizational boundaries, cultures, distance, and time. Compliance is easier to monitor. And, codification can contribute to the cohesion and feeling of solidarity in large and far-flung organizations and communities. Nearly all structured techniques to develop or share solutions or specify desired outcomes therefore entail some codification. However, excessive codification can be dysfunctional. Decision-makers therefore must choose how much to codify (the options here can range from a few key items to "everything possible") and how to do so (with options ranging from with complete precision or through broad principles).

• *Communication*. Ideas, however well codified, may not be effectively used if they are not persuasively and clearly communicated. Even knowledge that is embedded in physical objects requires effective communication – consumers must be persuaded to buy the objects and instructed in their use. Effective communication also requires comprehensible and convincing exposition. Techniques to make communication effective are age old, going back to at least the Greek rules of rhetoric. Now we have a profusion of techniques that cover a variety of circumstances and technologies, ranging from person-to-person communications, written reports, presentations, recorded videos and podcasts, and social media.

Whereas the five tasks above arise in technical activities (e.g. product design and testing) as well as organizational activities (e.g. coordinating product designers and testers), the next three apply just to organizational activities. And, the techniques we examine are ones commonly used by professionally managed organizations to concurrently develop and produce many artifacts.*

• *Commitment*. Making difficult to reverse commitments to strategic goals and policies before making tactical and reversible decisions helps coordinate choices "vertically" (so that the more tactical 'lower level' choices support the 'higher level' commitments); "horizontally" (so that choices at the same level support each other); and, "temporally" (so that later choices build on earlier choices.) Military planners pioneered doctrines and techniques – and established staff – for making strategic choices. Now such doctrines, techniques and staff have become a mainstay of strategic planning in large business and non-

* However systematic techniques for the three tasks date back to armies, navies, and civil administrations that long faced the problem of large-scale coordination, as we will see.

profit organizations where, as in the military, harmonizing vertical, horizontal, temporal choices is especially complicated.

• *Delegation*. Organized multiplayer effort requires delegating responsibility for managing systematically grouped and ordered tasks – and for the grouping and ordering. As mentioned, several templates support this delegation, grouping and ordering. These include multidivisional and matrix organizations that originated with large industrial companies; multinational and multi-practice law, consulting, and accounting firms; multi-specialty clinics and Health Maintenance Organizations (as substitutes for solo medical practices); and, networked organizations (that rely heavily on "outsourcing"). Project Management protocols help organizations manage complex one-off projects, typically to develop products and implement new systems. And process reengineering, six-sigma and 'lean' methodologies facilitate reassignment of delegated responsibilities and authority.

• *Incentivization*. The move from artisanal production to Henry Ford's assembly line manufacturing prompted a change from piece-work payment to paying high (five-dollar-a-day) wages for tasks specified by time-and-motion experts and monitored by foremen. Thus, while piecework encouraged artisans to produce more, Ford's wage plan relied on workers' fears of losing well-paid jobs to perform boring assembly line tasks. The subsequent shift to collaborative "knowledge work" on and off the factory floor has spurred a search for incentives and controls that promote teamwork without stifling individual initiative. These include bonus pools, stock-option programs, non-pecuniary incentives (such as job-enrichment and flextime), and 360-degree evaluations.

To further help us compare and evaluate alternatives we will use four sub-categories to analyze each kind of task:

• *Purpose* – the "why" of performing the task. (In our classification, tasks can serve several purposes).
• *Problems* and constraints faced in achieving the intended purpose.
• *Attributes*. We can think of each kind of task as producing "artifacts" (e.g. goals, conjectures, tests, checklists etc.) and characterize such artifacts using a variety of attributes.
• *Process* – "how" the task is performed, including but not just the systematic techniques used.

Figure 2 (next page) illustrates how these categories can be applied to analyze the task of goal and problem specification.

Figure 2: Analyzing Goal and Problem Specification

Purpose ("why") + **Problems**

- Stimulate search for alternatives
- Criteria (for search and evaluation of alternatives)
- Align choices (horizontally, vertically and temporally)
- Delegate, Control and Motivate

- Inconsistency or incoherence
- Comprehensibility/Communication
- Unintended (adverse) consequences
- Attainability/Acceptability
- Mismatch with specific circumstances

Attributes + **Process ("how")**

- Ambition and Audacity
- Time Horizon
- Direct, Surrogate or Oblique
- Comparative or absolute
- Level and Scope
- Complexity and Transparency
  - Precision and completeness of specification
  - Univariate, Indexed or Multivariate
  - Priorities and substitutions (if multivariate)
  - Horizontal variations and local discretion
  - Negotiability and Strictness of Enforcement
- Substitutes and Complements
  - Tacit norms, customs, and routines
  - Reports and Dashboards
  - Rewards and Penalties

- Top-down selections and edicts
  - Role models/values of founders or leaders
  - Generalized from prior experiences
  - Mandated by external authorities
- Systematized Multiplayer Techniques
  - New Product and Strategic Planning
  - Service Level Agreement templates
  - "Journey Maps" (Human Centered Design)
  - Objective and Key Result cascades

The arrow in the figure implies a loose – but not deterministic – "model" of alignment, namely that attributes and methods should normally reflect purposes and problems. This structure can make the analysis diagnostically useful (because misalignment suggests a practical problem).

Note that our classification and analytical scheme is just a simple "walking stick"[14] to help us find our way through a tangle of alternatives, not a "mutually exclusive and collectively exhaustive" taxonomy. For instance, goal setting can intersect with testing and evaluation and with codification in several ways. If goals are precisely codified, they can serve as metrics for testing and evaluation. However, amorphous or difficult-to-measure targets may have to be mapped into "proxy" measures for the purpose of testing or evaluation. Similarly, communication tasks cannot be fully separated from codification tasks. And, like Swiss-Army knives, techniques often span multiple tasks. Human Centered Design protocols are intended to help specify nonobvious goals for new products, develop creative conjectures for how these goals might be met, and rapidly test these conjectures.

Nonetheless, this rudimentary classification and analysis and examination of widely used techniques offers benefits comparable to those of a National Geographic river map and guide. It won't include the detail of military-grade satellite images or provide the hourly forecasts broadcast by the National Weather Service. Yet even the less-than-complete—and sometimes out-of-date information about access roads and campsites—provides a useful starting point for planning a canoeing trip: how to get there, what to carry, the class of rapids to expect and so on. Forest rangers and soil conservationists may use the guide for handy reference in their field work. Similarly, the seminar seeks to provide a general introduction and overview for a wide audience. If nothing else, this can protect us from charlatans and experts who oversell their nostrums. And, as suggested earlier, our analysis and examination of techniques can also reduce 'not knowing what we don't know' problems; suggest opportunities for cross-fertilization; and help diagnose problems (such as techniques that have become obsolete, conflict with each other, or no longer serve any useful purpose).

Noteworthy Artifacts (Module II)

The case histories that we examine in the second module of the seminar describe the evolution of noteworthy, many even transformational, technologies, products, protocols, and organizations. They include frozen foods, which changed what the developed world eats; shipping containers, which enabled the globalization of trade; personal computers, which led the democratization of computing; mammography, which helped reduce breast cancer deaths in the United States by 25%; tests and treatments that rolled back the HIV-AIDS pandemic; and, the evolution of Handelsbanken into one of Europe's largest banks, and of McKinsey and Company into a leading international consultancy.

The cases complement our preceding survey of tasks and techniques in the following way: The cases are much more detailed and comprehensive, but (unlike the material on techniques) they do not provide explicit prescriptions or precepts. Rather, any prescriptions and precepts must be inferred. But, just taking in the myriad facts contained in individual case histories is not enough. Drawing useful inferences requires filtering and organizing the facts. Our categorization of common tasks and review of popular techniques can help us do this.

Reciprocally, inferences from the specific cases can help fill gaps left by the more generic techniques. 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 develop more concrete heuristics for what warrants tighter or looser oversight and control even if the cases themselves do not make such heuristics explicit. Similarly, the cases can get us to think about "sweet spots" for the applicability of techniques. For instance, the frozen food case suggests that using Human Centered Design techniques could have accelerated market acceptance, by helping producers more quickly understand the true consumer benefits. But the techniques would have done little in the early days of containerized shipping when institutional and political resistance, rather than poorly understood user needs, was the main barrier.

(How studying specific cases improves the utility of generalized techniques and vice versa is comparable to the symbiotic benefits of reading great novels as well as studying 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 artifacts. As mentioned, good artifacts embody many choices that are well aligned with each other and with exogenous, contextual factors. But it is impossible for pioneering developers to anticipate the right constellation of choices. Rather, important additions and substitutions become necessary as the initial designs fail to perform. These can take decades.

Adapting the hard-won advances is usually easier but differences in goals or circumstances also often make simple copying infeasible. After 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.[15]And, a new wardrobe did not alter the Emperor's divine status.

Even copying seemingly simple innovations requires careful observation. The proverbial wheel, invented circa 3,500 B.C, required 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.

Studying the architecture of artifacts facilitates adaptation and replication: Knowing *how* the elements of an artifact work together and align with exogenous circumstances provides useful hints about what might need to be changed. And, because the logic of an intricate architecture is rarely self-evident, the history of its evolution can tell us much of the why's and the wherefores of its elements. Knowledge of the architecture and history of existing artifacts can similarly help pioneers transform entirely different domains. 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, who had been an associate at a prestigious law firm, did not copy the legal template wholesale. Rather he selected and adapted what he expected would fit the profession he was trying to create and invented the rest.

Finally, the case histories with real, flesh-and-blood protagonists highlight the ineffable roles of persistence, chance, leaps of faith and inspirational leadership — and the occasional ruthlessness. The path to lifesaving medical advances is often littered with deadly experiments innovators perform on animals and barely informed human subjects. Moreover, while the cases demonstrate the value of organized development, they also show individuals continuing to make vital creative contributions and bearing risks they cannot cast off in in some fictive anonymous market. And, by going beyond dry technique, the case histories just might inspire some participants in the seminar to seek pioneering challenges.

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.[16] 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.)[17]

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."[18] 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).[19] 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. As mentioned in the main text and shown in Figure 1, this knowledge includes values and norms, systematic techniques and tacit and contextual knowledge. 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 "upstream" science and "midstream" 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."[20]

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 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 as a result of an abnormality in the hemoglobin molecule. Although

* 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.

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 simplifies 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. [21] 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;[22]

• *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." (Molecular biologist James Watson who dismissed naturalist colleagues at Harvard who engaged in classification as "stamp collectors"[23] apparently shared Medawar's assessment).

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 blood-letting 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 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.

Requirements

Final Paper

Expected by noon, May 5, 2020 – and absolutely no later than two days before the deadline set by the registrar for submitting grades:

In lieu of a final exam, seminar participants will write a case history of a noteworthy artifact such as a medical treatment, software program, technique, or organization. The case history should include, to whatever degree information is available, a description and analysis of the:

- "Dynamics" and interactions of the common tasks we discuss in the seminar – how one choice led to and affected another.

- Roles, background, motivations, and risks of key individuals and organizations.

- Competitive or regulatory problems and user resistance encountered and how they were overcome

I will provide extra credit for reflections on how your case-history:

- Compares with case-histories of other artifacts discussed in the seminar or you are otherwise familiar with.

- Suggests, reinforces or causes you to modify generalizations you found in the seminar readings or which were discussed in the seminar.

- Has influenced your own long-term goals and career choices.

Teams of up to three students may work on a single case history. (Under no circumstances, four or more).* And please limit your paper to 15 single-spaced pages. Attach exhibits or appendices as you see fit but note that I will not give additional credit for bulking up the paper.

You will also be required to present your findings to other participants towards the end of the term and incorporate the feedback you receive in their final versions. And, as this is a capstone "incubator" course, papers may be turned into capstone projects.

You are strongly urged to pick an artifact from a list provided at the end of this syllabus and make your choice as soon as possible.

* I will grade the papers independent of team size: for example, two-person and three-person papers of the same quality will receive identical grades.

Schedule

Class #	Date	Topic
Introductory Case History		
1	15-Jan	Evolution of Medical Knowledge
Module I: Common Tasks and Techniques		
2	29-Jan	Goal and Problem Specification
3	5-Feb	Conjecture
4	12-Feb	Evaluation and Testing
5	19-Feb	Codification
6	26-Feb	Communication
7	5-Mar	Commitment (to strategic goals and policies)
8	12-Mar	Delegation
9	26-Mar	Incentivization
Module II: Noteworthy Artifacts		
10	2-Apr	Handelsbanken
11	9-Apr	Containers, Computers and Frozen Foods
12	16-Apr	Medical Advances
13	23-Apr	Wrap-up and Project Summaries

Daily Assignments

Introductory Case History

Evolution of Medical Knowledge

The history of medicine exemplifies efforts to develop knowledge that will "change the way things would naturally be," drawing upon – but not merely applying – knowledge of "the way existing things naturally are".

Readings:

• *The History of Medicine – A Very Short Introduction.* (Read the first chapter + Any one other chapter carefully and skim the rest)
• Seminar Overview and Course Requirements (Syllabus)

Questions:

After completing the reading on the history of medicine, please answer the following questions:

1. Think of any three innovators (such as Hippocrates or Sydenham), or groups of innovators (such as the French hospitalists): What were their implicit or explicit goals? What were their key general or overall choices (of platforms, paradigms, etc.)?

2. Basing your response on one chapter of your choice: What was the relationship between the development of "scientific" knowledge of "what already or naturally is" and the creation of diagnostic techniques and treatments that did not previously exist (to slightly modify Petroski's dichotomy)? Who were the leading developers of the former? How long were the lags between learning about the way things naturally are and the knowledge used to treat patients?

3. Again, focusing on any one chapter of your choice: In what ways did the state influence the development of medical knowledge?

4. What differences do you see in how practical knowledge is developed in medicine and in non-medical artifacts and practices?

Please enter your responses – just one paragraph per question – in the Google form below. (It would be prudent to type out your responses in a Word document and then cut-and-paste into the Google form at https://goo.gl/cNrlbU).

Module 1: Common Tasks and Techniques

Goal and Problem Specification

Readings/Podcasts

• Obliquity (John Kay podcast)
• Blogpost on Objectives and Key Results (OKR) systems OR Video Presentation on Objective and Key Results (OKR) systems
• The Balanced Scorecard (Norton Kaplan HBR)
• Goals Gone Wild (Bazerman et. al) (SKIM)
• *The Design of Everyday Things* (Don Norman) p. 218-221
• Establishing Design Requirements (Vincenti) (SKIM: DO NOT GET BOGGED DOWN IN THE DETAILS)
• Indeterminate Goodness of the Economy (Bhidé) (through the section, the Problem of Work)
• Technology of Foolishness (James March)

Optional

• In search of a better stretch target (Davies et. al)

Questions (to be answered at https://goo.gl/wvrSKW)

1. To what degree is the specification development process outlined in Vincenti's "Establishing Design Requirements" reading applicable outside airplane design? For instance, in health care, the military, business?* OR How is it like or unlike the process described in the *Design of Everyday Things?*

2. James March (Technology of Foolishness) raises the issue of choosing ends when you don't know what you could want – or will want – in the future. How is this problem different for organizations as opposed to individuals? What practical solutions do you see to this problem?

3. What kinds of goals or targets are best pursued obliquely (as John Kay puts it) and which ones directly?

4. What are the main similarities and differences you saw between OKRs, the Balanced Scorecard and Bazerman's *Goals Gone Wild?*

5. The Bazerman and Bhidé readings raise the issue of the level of aggregation (or "subsidiarity") in choosing ends i.e. which ones should be chosen by individuals, which by employers, and which by societies and governments. What criteria can you think of for choosing this level? And, what procedure would you suggest for making this choice?

6. Other observations from and reactions to the readings.

* In later sessions, we will also compare this process with the problem framing steps used in six-sigma, reengineering, human centered design and checklist techniques.

Conjecture

Readings

- *How strategists really think* (Analogical reasoning) (Gavetti and Rivkin)
- *Positive Deviant* (David Dorsey).
- *Design Thinking and Innovative Problem solving* (Datar and Bowler) **FOCUS ON IDEATION, PAGES 127-132**
- *Building a Best Practice Sharing Program that Works* (Lauren Keller Johnson)
- *Creative Benchmarking* (Dawn Iacobucci and Christie Nordhielm)
- Medicine, Management, and Mergers: An Interview with Merck's P. Roy Vagelos (Nancy A. Nichols) **FOCUS ON PAGES 106-108**
- *Drug Discovery 101* (Emily Burke)
- *The Five Why's* (Kanbanize)
- *What's your intuition?* (Gary Klein)
- *Blink* Wikipedia summary and Richard Posner review of *Blink*

Optional:

- *Six Secrets to True Originality* Grant
- *Strategic Decisions: When Can You Trust Your Gut* (Kahneman and Klein)
- *Imagined futures: Fictional expectations in the economy* (Beckert)
- *Positive Deviance Guide* (Tufts)
- *Beyond Best Practice* (SMR) Gratton and Ghoshal

Questions (to be answered at https://goo.gl/dEvkvX)

Pick any one systematic conjecture producing technique from: Analogical Reasoning; Positive Deviance; Design Thinking (Ideation); Best Practice/Benchmarking; Rational Drug Discovery; and, The Five Whys

1. For what kind of conjectures – or situations – is the technique best suited?

2. For what kind of conjectures – or situations – is the technique least suited?

3. What technique is it most unlike?

4. When and how can intuition serve as a substitute or complement to the technique?

Evaluation and Testing

Required Readings

- *Management Half-truth and Nonsense: How to Practice Evidence-Based Management*
- *Numerators Without Denominators: There Is No FDA for the Surgeon* (Spodick)
- *Drugs and Operations: Some Important Differences + Reply to Spodick* (Love)
- Assessing the Gold Standard – Lessons from the History of RCTs (Bothwell et. al)
- *Pros and Cons of Standardized Testing* (Columbia)
- *Why I don't Test Wine Blindly* (Altman)
- *The A/B Test: Inside the Technology That's Changing the Rules of Business* (Christian)
- *The Problem with Evidence-Based Policies* (Hausmann)
- *No-Nonsense Guide to Measuring Productivity* (Chew HBR)
- *Making Economics More Useful* (Bhidé) (SKIM Section 1 and conclusion only)
- *The Air-Propeller Tests of W. F. Durand and E. P. Lesley* (Vincenti) SKIM

Plus any TWO of:

- *Playing War Games to Win* (John Horn McKinsey Quarterly)
- *Excessive Ambitions* (Elster) SKIM
- *The Development of Discounted Cash Flow Techniques in U.S. Industry* (Dulman)
- *Mammography Case-Study*
- *Learning and Quality Control* (Miranti)
- *Controlled Experiments on the Web* (Kohavi et al) OR • *Online Controlled Experiments and A/B tests* (Kohavi and Longbotham)
- *The Truth Wears Off* (Jonah Lehrer)
- Plato's *Allegory of the Cave*
- *FDA and Clinical Drug Trials: A Short History* (FDA-Junod)

Questions: (submit answers at https://goo.gl/UDGplM)

Required question: What reactions did you have to any ONE of the "optional" readings (War games, Excessive Ambitions, Discounted cash flow techniques)

And any **two** of the following questions
1. What lessons do the examples of propeller testing and the No Nonsense Guide to Productivity measurement suggest beyond aircraft design and productivity measurement?
2. To what degree could A/B testing address the problems raised by Hausmann and Jack Love of randomized control trials? What are some other alternatives to RCTs?
3. What changes would you suggest to the FDA's drug testing rules?
4. How persuasive did you find Pfeffer and Sutton's critique of the "sorry state of the business idea marketplace?" How useful did you find the solutions they offer?
5. When is standardized and blind testing most and least useful?

Codification

Readings/Podcasts:

Checklists:

• Readings compiled into single pdf (comprising: Perspectives in quality: designing the WHO Surgical Safety; Checklist Atul Gawande's Checklist for Surgery Success; Atul Gawande interviewed by HBR's Katherine Bell; Justin Fox Blogpost on Gawande book; Ten Steps to Preventing Infection in Hospitals; Wall Street Journal Interview with Dr. Peter Pronovost; and Wall Street Journal Review of The Checklist Manifesto).

Knowledge Management:

• *Xerox creates knowledge sharing culture* (Powers)

• *If only we knew what we know* (O'Dell, Grayson). Focus on "The Process of Benchmarking and Best-Practice Transfer" (starting on page 159) and through the subsection Technology in the Service of Best Practices: If You Build It, Will They Come? (ending on page 166)

• *Establishing a Lessons Learned Program* (page 1-50) OR *Lessons learned process ensures future operations build on successes* (US Army Signal Center) OR *Lessons Learned the Army Way* (Crosman)

Technical Standards ("Design Rules")

• *Managing in an Age of Modularity* (Baldwin and Clark)

• *Notes on IT standardization* (Bhidé) OR *History of Standards Activity* (McGean) OR *Engineers and Government-Business Cooperation: Highway Standards and the Bureau of Public Roads, 1900-1940* (Seely)

Medical Protocols

• *Standardization in Action* (Extracts from Timmermans and Berg)

• *Emergence of Clinical Practice Guidelines* (Extracts from Weisz et al.)

Precision and Completeness of Codification:

• *Getting it Right the Second Time* (Szulanski and Winter)

• *Judgement Deficit* (Bhide) OR podcast at https://hbr.org/2010/09/the-big-idea-the-judgment-deficit OR *Formulaic Transparency* (Bhide)

• *The Use of Knowledge in Society* (Hayek) (Focus on Sections I-V)

Questions: (to be answered at https://goo.gl/dQ4Sl2)

1. What kinds of problems and tasks are checklists best and least suited for? Do you agree with Philip Howard's critique (in his review of Atul Gawande's book)?

2. What lessons or "takeaways" from the military/medical/business/IT codification readings might be applicable to other fields?

3. What alternatives can you think of that can replace or reduce the need for codification and standardization?

4. When is (answer any ONE):

- Loose or ambiguous codification better than precise, unambiguous codification? Conversely, when is precise, unambiguous codification better?

- Locally designed codification better than global codification? Conversely, when is global better?

- Partial specification better than complete or comprehensive specification (as suggested for instance in the Szulanski and Winter article)? Conversely, when is complete or comprehensive better?

- Discretionary adherence and enforcement better than non-discretionary adherence and enforcement? Conversely, when is non-discretionary better?

Communication

Readings, podcasts and videos:

Persuasion and Media Theory:

- Rhetoric Bragg et. al podcast posted at http://www.bbc.co.uk/programmes/p004y263
- Harnessing the Science of Persuasion – Cialdini's article based on his book Influence: The Psychology of Persuasion)
- Guardian podcast interpreting Marshall McLuhan's "medium is the message" claim (McLuhan's theories left much room for interpretation, as fans of Woody Allen know).

Visual representation of data and arguments:

- Gene Zelazny: Make Your Presentations Compelling – interview with author of Say It With Charts and its sequel Say It With Presentations and Zelazny remarks
- Tufte reader's guide – based on of Edward Tufte's Visual Display of Quantitative Information
- PowerPoint Debate – compilation of observations by Parks, Tufte and Zelazny
- Minto Pyramid Presentation (slideshare download)

Written Communications:

- *How to Structure What You Write* (Bierck, on Minto's Pyramid Principle) HBR
- *How to write a Memo or Report* (Williams, also based on Pyramid Principle) HBR
- *Vonnegut on Style and Shapes of Stories* (Maria Popova based on Vonnegut's presentation and essay included in How to Use the Power of the Printed Word anthology)

Making Presentations and Speeches

- *The Knockout Presentation* – HBR
- *For Presidential Hopefuls, Simple language resonates* (Boston Globe article)
- *20 Simple Steps to the Perfect Persuasive Message* (blog post)
- Nancy Duarte's 5 rules for presentations and a TedX East talk (video)
- Steve Job's presentations launching the iPod and iPhone (video)

Questions (to be answered at https://goo.gl/1N6XQ1)

1. What were the sharpest or most striking "general" differences (of differences "in principle") did you find in the assigned readings and videos? When would you follow one or the other principle?
2. What were the most striking "specific" lessons that you are likely to use in the future?
3. Which article or presentations did you find to be most effective in communicating their message? Who were the least effective? (List names; paragraph not necessary)
4. Which side do you support on the PowerPoint debate and why?
5. What lessons did you derive from the Steve Jobs presentations? What general and specific choices (e.g. about content, structure, delivery, visual aids, etc.) did Steve Jobs make? To what degree do his presentations confirm, extend, or challenge the other material you read or saw?

Commitment (to "Strategic" Goals and Policies)

Readings

- *Competition and Business Strategy in Historical Perspective* (Ghemawat)
- *Gaining Advantage over competitors* (McKinsey Quarterly compilation)
- *What is Disruptive Innovation*? (Christenson, Raynor and McDonald)
- *Clay Christensen's theories are great for entrepreneurs, but not executives* (Bhidé and Ghemawat)
- *The Development of Discounted Cash Flow Techniques in U.S. Industry* (Dulman)
- *Operations Research vis-à-vis Management* (Thomas) OR *History of Progress Functions.* (Dutton)
- *Military Strategy: Encyclopedia Britannica Entry* (Cohen)
- *Strategy Needs Creativity* (Brandenburger)

Optional reading and podcasts

- *Critical Tasks* (Chapter 11 in Bhidé's Origin and Evolution of New Businesses)

- Sun Tzu podcast and/or The Art of War

Questions: (to be answered at https://goo.gl/xnK5nd)

1. What ideas in the required or optional readings did you find to be most in conflict? Most complementary?
2. What relationship do you see Discounted Cash Flow (Dulman) and business strategy techniques? OR What similarities and differences did you see in the development and substance of military and business strategy techniques?
3. Why haven't Progress Functions (Dutton) or Operations Research (as discussed by Thomas) become as popular or widely used as Porter's Five Forces, Christenson's Disruptive Technologies, and Discounted cash flows?
4. What questions do the readings raise in your mind that we should discuss in class?
5. Other optional observations.

Delegation

Readings

- *Note on Organizational Structure* (Nohria et. al) **Focus on 'Traditional Organizational Structures' p. 4-6**
- *Extracts from Strategy and Structure Book Review* (Krooss)
- *Spread of Multi-divisional Form* (Fligstein) **Focus on highlighted material**
- *Strategy followed structure: management consulting and the creation of a market for "strategy," 1950–2000* (McKenna) **Focus on highlighted material, mainly on p. 158-161**
- *Diversity in Diversity* (Scranton) **Focus on highlighted material**
- *The Halfway House: Coordination through Organizational Authority* (Amar Bhidé) **p. 46-51**
- *A Brief History of Lean* (Lean Enterprise Institute)
- *Six Sigma and Project Management* (Stauffer)
- *Encyclopedia Britannica entry on the History of the Organization of Work.* **Only highlighted material**
- *Business Process Reengineering* (Wikipedia March 20, 2019 download) **SKIM**
- *Venturesome Consumption* (Bhidé). **Only highlighted material**
- *Reengineering Work* (Hammer)
- *Excerpts from Encyclopedia Britannica entry on R&D.* **Only highlighted material**
- *AMA Handbook of Project Management* (4th Edition) **SKIM Chapters 1, 2**
- *Note on Project Management* (Svann). **Highlighted material on pages 1 and 2**

Optional readings

- *Scientific Management, Systematic Management.* (Nelson)
- *Organizational Structure and the Multinational Strategy* (Fouraker and Stopford) p. 48-51
- *Some personal perspectives on research in the Semiconductor industry* (Moore) **Highlighted material**
- *Excerpts from Encyclopedia Britannica entry on Bureaucracy*
- *The Focused Factory* (Skinner)
- *Project Management Overview Presentation* (Tufts workshop)
- *Technical Progress and Co-invention* (Bresnahan and Greenstein) **Only highlighted material**

Questions (to be answered at https://goo.gl/6j9Opn):

We can (roughly) classify techniques discussed in the assigned readings into the following categories: 1) Structuring sub-units of large organizations (based mainly on Chandler's work). 2) Reorganizing organizational structures and processes ("lean", "business process reengineering," six sigma) and 3) Project management (including R&D).

1. How have these techniques affected – and been affected by – the "multiplayer" development of new artifacts (and the practical knowledge they embody)?
2. What similarities and differences in the techniques and/or in their development and adoption do you find most striking?
3. What is your overall "takeaway" from the readings?
4. Other optional observations.

Incentivization

Readings;

- *Keeping the Best: Essential Retention Strategies* (HBR) (**SKIM**)
- *Miscellaneous incentivization readings* (QUICK SKIM)
- Daniel Pink videos
- *Did Henry Ford Pay Efficiency Wages?* (Raff and Summers)
- *A Theory of Human Motivation* (Maslow)
- *A Historical View of Theory Y* (Carson)
- *Nature of Man* (Jensen and Meckling) **FOCUS** on 'The Psychological model of Human Behavior' that starts on p. 14

Questions (to be answered at https://goo.gl/Emb5vv):

1. What "new takeaways" from the readings (or videos) on employee retention and motivation could you or an organization you are familiar with have fruitfully applied, and in what specific situations?

You don't need to describe the specific situations where the takeaways could have been applied in your write up, but please be prepared to describe them in class.

Also, the "new takeaways" don't have to be ideas that you had literally never thought about or which are completely non-obvious; they can be things that that you had not given serious thought to and ideas that are obvious once pointed out. Also, the takeaways need not be explicit in the readings but merely prompted by the readings.

2. The practical utility of which propositions do you have the most doubts about?

3. What relationship do you seen between an "efficiency wage" (Ford), "hierarchy of needs" (Maslow), and Theory Y (McGregor)? How relevant and useful are these ideas today?

4. Other optional observations.

Module 2: Noteworthy Artifacts

Handelsbanken

Readings

• Handelsbanken.: 2002 (A), HBS No. 115-018.

• Section on "Longevity and Growth" in Chapter on "Missing Attributes" in Origin and Evolution of New Businesses, Bhidé 1999.

Study Questions (for you to think about)

What makes Handelsbanken different from other large banks and what tradeoffs does its distinctiveness entail?

To what degree does Handelsbanken face the "generic" spurs and constraints to growth (described in the "Missing Attributes" chapter)? What additional spurs and constraint arise because of banking – and Handelsbanken's distinctiveness distinctive approach?

What risks and opportunities does a bank in general – and Handelsbanken in particular – face in entering the Baltic and UK markets? How, if at all, would you change Handelsbanken's model in Sweden to the Baltics?

How do you weigh the risks and opportunities in the Baltics and UK vis-à-vis growth in Norway, Denmark and Finland where Handelsbanken already has a presence?

Questions to be answered at https://goo.gl/yN5Fkj

As Par Boman, I would recommend Handelsbanken make a serious commitment to growth in (check all that apply):

[] Norway and/or Denmark and/or Finland

[] The Baltic Countries

[] The UK

[] None of the Above

[] Other (please specify)

Because:

[Enter your top reason]

[Enter reason 2]

[Enter reason 3]

Optional Additional comments []

Containers, Computers and Frozen Foods

(There is a lot to read. Please focus on the story: the plot, the characters, and organizations rather than the author's take or analysis and skim as indicated).

• *External Economies and Economic Progress: The Case of the Microcomputer Industry* (Langlois).

• "Not Only Microsoft: The Maturing of the Personal Computer Software Industry, 1982-1995" (Campbell-Kelly) **SKIM**

• Levinson interview with Dan Wang

• *Container Shipping and the Decline of New York, 1955-1975* (Levinson) p. 49-80

• *The Economies and Conveniences of Modern-Day Living: Frozen Foods and Mass Marketing*, 1945-1965" (Shane).

• *Lighting the Path to Profit: GE's Control of the Electric Lamp Industry, 1892-1941* (Reich). **SKIM)**

•From Novelty to Utility: George Westinghouse and the Business of Innovation during the Age of Edison (Usselman. **SKIM**

Questions (to be answered at https://goo.gl/CGO0JT)

Think about the similarities and contrasts between all the cases but for the purposes of the pre-class write up focus on just ONE of the following artifacts: Microprocessors (Personal computers), Shipping Containers, and Frozen food

1. What did you find to be the most notable features in the evolution of the artifact, especially in terms of who did what when and why? And how do these features compare with those of the other artifacts you might have read about elsewhere?

2. How does the evolution of the artifact fit – or not fit – any of the earlier readings and discussions (on goals-setting, conjecture etc.) in the seminar?

3. What questions do the readings raise in your mind?

4. Other optional observations.

Noteworthy Medical Advances

Readings:

- *Constraining knowledge: Traditions and rules that limit medical Innovation* (Bhidé)
- *Excerpts from Book Proposal* (Bhidé and Datar) FOCUS ON HIGHLIGHTED MATERIAL

Case Histories of Significant Medical Advances (ANY THREE):

- *HIV/AIDS: Tests and Treatments*
- *CTs*
- *MRIs*
- *Ultrasound*
- *Mammography*
- *Endoscopy*

Questions (to be answered at https://forms.gle/uQKTyvMsA8AWrsks6)

1. What did you find to be the most notable feature (or features) of the case-histories? And how do these features compare with the development of non-medical artifacts you read about in the previous class?

2. How do the medical advances fit – or not fit – any of the earlier readings and discussions (on goals-setting, conjecture etc.)?

3. What is your viewpoint about the issues raised in the book proposal? Are there any other issues which you think are important?

4. Other optional observations.

List of suggested paper topics

Objectives and Key Result (OKR) systems
Balanced Scorecards
Positive Deviants
Design Thinking
Machine Learning/Big Data/Artificial Intelligence
Best Practices and Benchmarking
The Five Whys/Fishbone analyses
Six Sigma
Rational Drug Discovery
A/B testing
War Gaming
Simulations (including Agent Based Modeling)
Checklists
Professional Uses of Social media (e.g. for external marketing, intra-organizational coordination)
Professional Uses of Story telling
Meetings (Real or Virtual)
Technical or Engineering Standards
Medical Protocols and Standards
Project Management
“Agile” or “Lean” Processes
Integrative review of any of the “tasks” (e.g. Goal Setting, Conjecture etc.)
Any medical innovation (from the Victor Fuchs and Harold Sox list)

Any non-medical technology or artifact that has made as significant impact on modern life (such as the internet, mobile phones, the web, spreadsheets) that we did not cover in the syllabus

Notes to Overview

[1] Simon (1996)

[2] John Adams, the second President of the United States had a different view of higher education. In 1780 he wrote: "The Science of Government it is my Duty to study, more than all other Sciences: the Art of Legislation and Administration and Negotiation, ought to take Place, indeed to exclude in a manner all other Arts.—I must study Politicks and War that my sons may have liberty to study Mathematicks and Philosophy. My sons ought to study Mathematicks and Philosophy, Geography, natural History, Naval Architecture, navigation, Commerce and Agriculture, in order to give their Children a right to study Painting, Poetry, Musick, Architecture, Statuary, Tapestry and Porcelaine."
letter to Abigail Adams, after May 12, 1780.—Adams Family Correspondence, ed. L. H. Butterfield, vol. 3, p. 342 (1973).
Downloaded from https://www.bartleby.com/73/481.html see also
http://www.newenglandhistoricalsociety.com/john-adams-writes-to-abigail-i-must-study-politicks-and-war/

[3] John Kay's review (downloaded on August 21, 2018 from https://www.johnkay.com/2018/08/10/the-secret-of-our-success-a-review/) succinctly summarizes Henrich's argument.

[4] We will however review techniques for individual use to illuminate the distinctive features of collectively used techniques.

[5] Burke, Peter. 2000. *A Social History of Knowledge: From Gutenberg to Diderot*. Cambridge, U.K." Polity Press. p. 44

[6] Elster (1993) p.51.

[7] Elster (1993) p.71

[8] Vincenti p 208

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

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

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

[12] Usselman (1992) p. 254

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

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

[15] 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

[16] 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).

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

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

[19] Shapin p xxx

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

[21] 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.

[22] See for instance Hayek's distinction between scientific and specific knowledge.

[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

[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