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At the age of nine, young Linus had made up his mind to be a chemical engineer. Growing up in Portland, Oregon, he was fascinated by the natural world, and devoured books with unnatural appetite. Linus excelled at school, especially impressing his chemistry teacher, who awarded him an extra semester of credit for his work. By the fall of 1916, the 15-year-old senior was already prepared to graduate from high school. Linus had all the necessary credits, except for two history courses. Nevertheless, that September, he decided he was uninterested in *American History I* and *II*, and left the school without a diploma.

Still eligible to enroll in a nearby agricultural college, Linus resolved to take as many mathematics courses as possible, and to major in chemical engineering. Back home, his mother envisioned a different future for her son. She firmly opposed higher education. To her, college was "effete and strange." In her mind, a real man was self-taught, as the men in her family had been. She insisted that Linus work at a local machine shop and start bringing home regular wages.

Sensing that his life's goal was threatened, Linus disobeyed his mother and enrolled in the Oregon Agricultural College at the age of sixteen. There, he won the support of nearly all the faculty he met. After graduating, he immediately continued his education to earn his Ph.D. from Caltech (Goertzel 21-24). Seventy-three years and two Nobel Prizes later, Professor Linus Pauling was world-renowned for his contributions to the fields of Organic Chemistry, Molecular Biology, and Medicine. In a 1990 interview, he said the following (a quote I would find on the first page of my first Chemical Engineering textbook): "Why?" he asked, referring to his earth-shattering contributions to fields in which he had never taken courses, let alone earned any degree. "Why am I able to do these things? You see, I got such a good basic education in the fields where it is difficult for most people to learn by themselves." ("Linus Pauling, Ph.D. Interview")

It's tempting to interpret Ben Franklin's vision for multidisciplinary education as a curriculum of quantity. Adding more departments and requiring the study of far more varied subjects is what, on the surface, he mainly announces in *Proposals Relating to the Education of Youth in Pensilvania*. On first pass, the document seems unremarkable. One would be hard-pressed to find an American university today without an English department (even the Massachusetts Institute of Technology offers a major in literature), or a science class without a laboratory component. Students who might major in physics are still exposed to courses in writing, history, and foreign languages. General requirements ensure that students learn, as British educator Thomas Huxley wrote, "something about everything, and everything about something." At least today, Franklin's ideas for a multidisciplinary education are widely adopted, and it seems that his vision has been achieved.

Or has it? Is it true that an education needs only to be diverse to be of quality? Is a university which provides its students with courses in both the arts and sciences doing enough to prepare them for their most effective citizenship? Perhaps Benjamin Franklin's proposal for America's first university implies teaching youth something more.

* * *

In the fall of 1973, Ashok Gadgil arrived at the University of California at Berkeley to enroll in the physics Ph.D. program. After completing both his bachelor's and master's degrees in India, Gadgil was in for a shock – and a reaffirmation of purpose – when he arrived in the United States. "Two things really struck me while I was in graduate school," he said. "One was the high level of affluence in the United States. The second thing was getting a sense of how important it is to have science applied to address problems that are societally significant. They may not be scientifically significant, because the basic science is well understood, but nobody had bothered to take the final step to convert that into a useful technology."

In the 1990s, Gadgil began investigating the use of ultraviolet (UV) radiation in killing bacteria and viruses. The motivation for his work came from his first-hand knowledge of epidemics: while living in India, Gadgil found himself in the midst of a drinking water hepatitis infection which affected many of his friends and neighbors. Gadgil was familiar with the global problem of diseases spreading through public drinking water, one of the most rapid and lethal modes of disease propagation. In 1993, after a cholera outbreak in Bangladesh that resulted in over 10,000 deaths, he resolved to apply his knowledge of physics and engineering to a problem which was sociological, civic, and medical in nature.

That summer, together with a student, Professor Gadgil found a certain wavelength of UV light that could potentially disinfect water at "half a cent per ton." Since then, Gadgil's UV Waterworks System, and scaled variations of the original invention, have saved countless lives. The new application has improved the quality of life in countries ranging from Honduras to the Philippines, and his technology continues to be one of today's most important tools in cleansing drinking water for large populations (Brown 140-143).

What is Gadgil's greatest contribution? As far back as the 19th century, UV light was known by scientists to kill bacteria, and for centuries, public drinking water systems had suffered from infection. If so, why did it take until the arrival of Ashok Gadgil to consolidate the two, into what is a technologically simple invention? Understanding Professor Gadgil's story makes the answer clear: a strong education in the hard sciences, a first-hand understanding of world health problems, and a moral conscience led to his role in pioneering effective and economically persuasive water purification.

Ashok Gadgil's total education was more than a product of his schooling, but his success reveals a valuable lesson for formal education. Gadgil's multidisciplinary exposure, plus a spark to integrate widely separate sections of his knowledge, made him a worldwide lifesaver. That *spark*, the inventor's spark, can be taught in school. And that spark is the key to Franklin's vision. Released in it are what I believe to be the final, necessary parameters to a multidisciplinary education with a relationship to the world.

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Stroll along Walnut Street, near 36th, today, and you will pass a large window display in the Penn Bookstore. Aside from the Franklin-faced mannequins porting overpriced Penn sweatshirts, a large portrait of Ben Franklin hangs, staring forward at the Annenberg Center. Surrounding the portrait in large print are the many classifications one might use for Franklin's life. Among the terms in the display are *Diplomat, Scientist, Writer, Publisher,* and *Civic Leader*. To the left is the word which I believe is the most central of all to Franklin's personality and vision for education. Aside from his huge role in our nation's history, the Penn Bookstore reminds passersby, Benjamin Franklin was also an *Inventor*.

What is invention? Many might flatly answer with "the child of necessity." Certainly, most inventions respond to a need, but a need will not necessarily inspire innovation. Inventing requires knowledge of the world and its properties, and an attitude that it should be challenged – and can be changed. Attitude is the key ingredient, not genius or brilliance. Albert Einstein spent his college years around books and meetings about the philosophy of science. His observations of the pattern of history gave him the insight that nothing is sacred in scientific knowledge. When his mind rolled around to the experimental inconsistencies surrounding the 19th century theory of light, he was more inclined to overhaul the conventional theory than to scramble to explain it (Howard). Richard Feynman, another Nobel-prize winning physicist famous for his irreverent attitude, wrote "Science is the belief in the ignorance of experts" (Feynman 187).

The two fundamental methods of invention are *integration* and *differentiation*. To invent by integration is to combine two or more ideas on any level. It's that simple. Most inventions can be attributed to integration. To try naming a few physical inventions: the outboard motor on a boat, the ATM machine, or the city mural are all products of integration. One of many academic ideas attributed to integration might be the computer science of *artificial evolution*, where natural selection is applied to "embryonic" circuits until they evolve into something which can perform a calculation as complicated as the cube root of an input (Koza).

Differentiation feeds on integrative inventions. What if, in creating combinations, an inventor combines too many things? That invention could still be useful and innovative, but was something overlooked? Maybe combining less would have yielded something else? Differentiation is picking apart an existing idea – questioning what we take for granted about something. To invent by differentiating, make a list of the parts, attributes, and assumptions of an idea; delete or replace any one; put it all back together; and step back to see what you've made. It's bound to be novel, maybe even useful. Many highly effective art movements, such as impressionism, have evolved this way. Why does painting have to be detailed? The recently publicized $100 Laptop project of the MIT Media Laboratory is also a "differentiated" invention; the object is to create a portable computer with far less ornamental features than an "obese" personal computer. The hand-crank powered fully-functional laptop will be mass produced and distributed to students in developing countries, to connect them with the massive knowledge network of the world wide web (Negroponte).

These two methods of invention do not explain all inventions, how the inventors themselves came up with the idea, or how to solve from a problem. Inventors use both processes in many inventions. However, if we can map inventions on these terms, we clearly see what an inventor should know.

To integrate, an inventor's knowledge must have breadth and depth. She must know of the problems in other fields. She must understand the different ways of thinking in different fields. She must know at least how to start any intellectual excursion in a field besides her own. More than just knowing about other subjects, she must above all appreciate their value and potential in relating to her field. A good anthropologist understands the basics of microeconomics, and a biologist commonly uses statistics. There are many more combinations and reapplications waiting to be made. Furthermore, to integrate, an inventor should also possess a depth of knowledge in a certain field. To identify a worthwhile problem, one must often be at the raw edge of knowledge and understand what has been solved and left unsolved. It took a medical scrub technician like Thomas Fogarty, present at many cardiovascular surgeries, to invent the balloon catheter in 1961. Of course, Fogarty was also a fly-fisher and used his skills in the sport to tie together the first prototype (Brown 12-17). An inventor should be an expert in something.

On the other hand, to differentiate, an inventor must know how to laugh at the world. He must have the attitude that nothing is sacred and that everything is worth questioning. He must feel that there is no reason for light switches to be shaped the way they are, that cell phones don't necessarily need to connect to central towers, or that a story does not have to be told in chronological order. The more fundamental the assumptions he challenges, the more significant and disruptive the final idea.

Benjamin Franklin, the inventor, proposed a school that would graduate inventors. His multidisciplinary curriculum communicates more than a lot of separate knowledge; it displays the connections between disciplines as explicitly as possible. Franklin strings together seemingly disparate subjects, moving seamlessly from economics to mechanical engineering, sliding from history to oratory. It is clear from the proposal that Franklin's "youth" would study many different subjects over the course of their education. But multidisciplinary means more than learning many *different* things. It is about learning what the different fields *share*.

On the surface, there's not much in common between businessmen and journalists. Businessmen create reality out of appearances; journalists work to restore appearances back to reality (in theory). What they must both do well, however, is communicate their ideas with language. There are few things more glaring from Franklin's proposal and his footnotes than his insistence on teaching language, the English language, and teaching it in all its forms. No professional can escape the need to communicate, and often a person's communication skill can act as the soft link in an entire chain of accomplishments. Writing and speaking are the most efficient ways of communication, and their refinement can only increase the traffic within and between fields. As Ludwig Wittgenstein famously wrote in *Tractatus Logico-Philosophicus*, "The limits of my language mean the limits of my world."

* * *

At a recent "case-interview workshop" deep within Hunstman Hall, a representative from the consulting firm Mercer Oliver Wyman addressed a packed crowd of business-casual upperclassmen and essentially said, "When we hire you, we don't care what you know, we're interested in whether you can *think*." Undergraduate education today provides a substrate for learning how to think. In the age of extreme specialization, teaching for a certain occupation is inefficient. What is efficient is for college to explicitly (but not exclusively) focus on teaching thinking. The end is to learn mindset over facts. Absorbing the original, the basic, the crucial – the ability to think critically – is the highest purpose of undergraduate education.

I experienced one of my largest educational disappointments last semester in Molecular Biology. It was my first time learning biology in five years, and the first two weeks for me were intellectually incredible. I felt I had gained a new way of analyzing the world. I admired the broad new principles that tied together much of what I had learned in chemistry and physics, and I considered switching my major. I couldn't wait for the rest of the semester, but I would be let down. To use a softening simile, what happened next was akin to having spent two weeks learning how an airplane flies, and taking the next 10 weeks to memorize the nuances among Boeing passenger jets. Most of the course was dedicated to learning arbitrary special cases of the physical and chemical principles that govern arbitrary types of cells; a large part of each test was pure memorization. As an undergraduate, replacing the class with an advanced chemistry course would have been far more worthwhile.

Retooling a standard biology course around to teach thinking over knowledge is remarkably simple. Small detail changes can shift the entire bearing of the course. Although the possibilities are endless, Ben Franklin offers a few basic suggestions. First, make a class hands-on and minds-on. True, my classmates and I spent three hours every Tuesday night in the undergraduate laboratory, and most of it involved pipetting and centrifuging our test tubes, but we were following a cooking recipe – not designing our own experiments. Even in writing seminars, students learn writing *by writing*, not by re-copying successful essays; so what exactly were we doing in that biology lab? For studying the natural sciences, Franklin advocated "excursions to neighboring plantations" where youth would not only observe, but also reason about applied agronomy. When discussing student debates, he emphasizes that students would learn to apply logic and reason, to think with agility.

If a course wants to teach thinking, it must test thinking. In the same semester, my two engineering courses were my largest educational satisfactions. In Biomechanics and Material-Energy Balances, I memorized no formulas and no constants, but picked up a complete engineering way of thinking. Our tests were open anything-you-can-fit-in-a-backpack, and yet remained highly challenging. Each test problem was nothing more than a puzzle, and the sciences of chemistry and physics were the rules for playing. When a course aims to teach thinking, assignments and examinations must be problems, not questions. At this point, am I more prepared to design an open chemical system, or test the presence of a new pathogen?

Breadth and depth are not enough; an inventor needs attitude. An inventor is prepared to think in the future, appreciate the fallibility of the status quo, and have a strong sense of perseverance – both with himself and against outside opinions. Benjamin Franklin knew this well. His entire life was occupied with nudging the status quo forward, from the first issue of *The Pennsylvania Gazette* to his role in shaping the American Revolution. In his very first footnote, Franklin quotes Charles Rollin at length about the perils of "blindly following the footsteps of those who have gone before us." Franklin does not propose, however, to explicitly teach youth to question authority. Instead, he repeatedly advocates the teaching of history. What can history show about change, the fallibility of the status quo, and attitude? *Everything*. If there's a consistently observable and predictable pattern in history, it is that of innovation, initial resistance, and widespread change. The smartest lesson from history is to keep an open mind.

* * *

Did Ben have his way? By this interpretation, we should evaluate whether students receive a multidisciplinary education, if they have sufficiently learned how to think, and whether we encourage the right attitude. Or even better, one can open a recent issue of the *Pennsylvania Gazette*, "the alumni magazine of the University of Pennsylvania," and read the latest alumni profiles, articles on what five selected Penn graduates are currently working. But giving examples is definitely futile. I could expound on how Penn is one of the most interdisciplinary institutions in the world; I could mention how few, if any, other universities surpass Penn's quantities of diverse research nodes and the links between them. On the contrary, I can list undergraduate classroom experiences, or complain that the physics department doesn't collaborate enough with the veterinary school. Even if we could authoritatively calculate an IBHHHW quotient, say "36.0 ± 0.2," it would leave us wondering about what's next, anyways. Asking "are we there yet?" is not the right question; asking "where are we going?" is better.

As a resident of Florida, I can frankly say that building strong walls for a house is one thing; designing a house to withstand a hurricane is quite another. Likewise, it is far clearer, more flexible, and more focused to describe a university's mission for undergraduate education in terms of *ends* than in terms of *means*. More than specific initiatives such as the Weiss Tech House, or the Engineering-Wharton product design course, the entire educational mission should be invention and problem-solving. With invention as the ultimate focus of a Penn education, everything else will fall into place. Like reading *The Economist* or checking our email, creating an inventive environment is something of which we can always do more. This is how Penn can rise "from excellence to eminence" (Gutmann).

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