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Success Through Failure
The Paradox of Design
by
Henry Petroski

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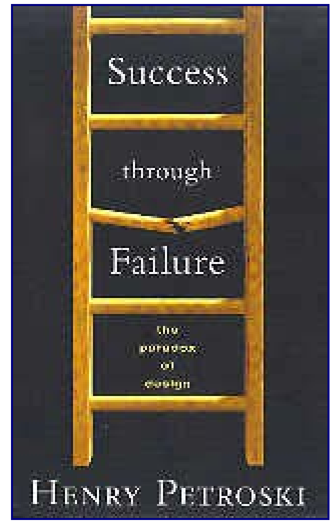

During my required two years of ROTC(1) at LSU, I learned one of the biggest lessons of my life: *Make your biggest mistakes first.* Before that time, I was a perfectionist and never attempted anything until I was sure I would succeed, and when I failed, felt very bad for some time afterward. My lesson came from the most unlikely place: in a Military Science course. In the mortar class, I learned that the field observer who has his sights on the target, always give coordinates to over shoot the target by a wide margin on the first mortar round lobbed at a target. He notes how far the round over shot the target. Then gives coordinates certain to fall short of the target for the next lob. Again he notes how far the round under shot the target. He calculates coordinates now which will overshoot target by half the original overshot, fires a round; repeats same for undershot. By bracketing in on the target this way, the observer minimizes the amount of time necessary to hit the target, not by aiming directly at it (which he cannot do, only guess at), but by purposely failing systematically until a test round hits the target at which time the observer radios back, "Fire for Effect", and a barrage of mortar rounds are unleashed guaranteed to hit within the target area, every one!

Later in one of my careers, as a systems analyst for computer systems, I would learn how to code and specify coding for a Binary Search in order to find an object in a list whose exact location in the list is unknown. After using this technique on several projects, I remembered the mortar sighting lesson and realized that it used, in effect, a Binary Search procedure. The two processes used the same method: overshoot, undershoot, until you have bracketed in on the target in the minimum number of tries.

Failure as the path to success is the theme of Henry Petroski's book. He says on page 3: "Past successes, no matter how numerous and universal, are no guarantee of future performance in a new context." For mortar sighting, this is true because every target represents a new context, and the unknowns of the new context are part of the unknown of hitting the target. But the converse to his statement is also true, as Thomas Edison showed conclusively with his light bulb invention, "Past failures are no guarantee of future failures." If that were not true, we would have no inventions to improve our lives. Few people understand the importance of failures in creating a new design more than inventors.

His look at failures of large scale designs in bridges and buildings provide ample examples for how error-fraught is the process of "success-based design extrapolation."

[page 8] Such examples provide caveats against success-based extrapolation in design.

> **Past success is no guarantee against future failure.**

When you extend a successful design, you enter the realm of the unknown which no amount of successes with the original design can make you feel comfortable. Designs are actually maps, and as Alfred Korzybski has emphatically stated, "The map is *not* the territory." And when the territory is a narrow suspension bridge using the same design of a wider suspension bridge, as was done with the Tacoma Narrows Bridge in 1940, a recipe for disaster is but a high wind away.

In his first chapter "From Plato's Cave to PowerPoint" Petroski takes us step-by-step through all the early inventions used to project images on a wall up to the 21st Century's computerized PowerPoint presentations. In the Plato's Cave metaphor, Socrates explains that cavemen are bound in chains to sit on the floor of their cave looking at the shadows cast on the far wall by activities outside in the cave. But they know nothing of the outside world, only the shadows which they examine(2).

> **[page 12] Socrates then imagines that the prisoner is taken out of the cave and exposed to the direct experience of the sun and everything that it illuminates. At first the prisoner would be blinded by the brightness, but in time he would come around to see the world outside the cave for what it is. If he then returned to the cave and sat among the prisoners who had remained there, his descriptions of the sources of the shadows and external reality would be met with skepticism. Better to remain in the cave, the prisoners would say, rather than to go away and come back without clarity of vision.**

Every inventor or innovator leaves Plato's Cave to view the real world unsuspected by those in the cave, and upon return is mocked by those who remained behind in the cave. The innovator may no longer be invited to discussions of her colleagues when she begins to explain what she experienced outside the cave of her profession.

Petroski goes into detail describing the evolution of devices for projecting images on a wall to audiences. Along the way he takes us from blackboards to Magic Lantern slides, to halotypes, to animated cartoons. In a time before movies, when fading out one slide as another slide rose into view ('dissolving view') was the height of technology, one Mr. Constant became famous for bringing animation to audiences.

> **[page 23] The English slide painter C. Constant "made himself immortal by painting the original of the world-famous slide of the sleeping man swallowing rats." . . . As one attendee of a "Magic Lantern show given to poor and destitute children" recalled the (rat-swallowing) gentleman a year later, "He was our star turn, our living picture, our cinema. He was everything. He made up for all the long, and sometimes dreary lectures to which we had to listen, even though it was 'accompanied by Dissolving Views.' We wanted life and movement, and when he was thrown on the screen the grand climax of the whole entertainment had been reached, and enjoyment was complete."**

The audience reaction to animation seems to match that to the omni-present YouTube movies which have replaced the previous still images of websites. One lecturer claims to have over 2300 lectures on a wide variety of subjects available on YouTube, and schools all over the world are using these lectures in their classrooms. YouTube is the modern day equivalent of the rat-swallowing man.

As Petroski leads us through the evolution of 35 mm slides(3), overhead projectors using grease pencils, and various other mechanisms, I can recall from my own experience the problems with these various means of presentation over the decades. Now computer projection of PowerPoint slides have completely replaced the 35 mm slides for all new presentations. Welcome to the Age of "Death by PowerPoint" when speakers give handouts of their PP presentation, display the same slides on the screen, and read the slides verbatim! (Page 37)

Another aspect of success through failure comes when some product, ineffective for the use intended turns out to be wildly successful for an unintended use. The most prominent one I can think of is Post-It Notes. The inventor at 3-M had completely failed at his task of producing an effective glue! But he soon discovered a use for a partially effective glue for attaching these little colorful Post-It notes to various objects in the office and at home. Play Doh was a product that had been used for cleaning certain filters which were going out of use. Someone gave some to his wife and she discovered her kids loved to squeeze it and shape in their tiny hands, and a new kind of toy emerged. Petroski discusses the origin of Teflon, another ubiquitous product in the latter half of the past century.

> **[page 42] . . . an inventor can stumble across something novel and useful while trying to design something entirely different, the way Roy Plunkett discovered Teflon while looking for a new refrigerant.**

When a person walks into a new building, he usually notices the beauty of the place, but if he be an engineer, he notices the problems with the place and how the place could be improved. Every design an engineer sees suggests novel designs based on that design. One can always notice the output of new graduate engineers in the design of packaging, handles, shapes, and functionality of traditional objects. Sometimes the new designs work, sometimes they are dismal failures. Fiskars made a new and improved garden shears. I bought one to replace my old one which kept losing its handles. The new shears broke within a month. One of the 18" blades was made of a fragile pot metal and it simply broke off under normal use. I complained to the company and they sent me a new shears. I kept the handles from the broken shears and use them to replace the handles on my old shears which had both blades made of tempered steel instead of the new, improved Fiskars shears which had only one blade of tempered steel. Seven years later my old shears with the new handles are still being used and I avoid the fragile newer shears.

> **[page 42, 43] Designs always beget designs. However, since design is a human activity, it is also an imperfect one. Everything designed has its limitations and its flaws. This fact of design is what leads to constant change in the things around us and our behavior involving them. Inventors, engineers, and other professional designers are constantly criticizing the world of things, which is what leads to new designs for new things. The successful new thing is one that does not fail in the way that what it is intended to supersede did. This is why failure is the key to design. Understanding how things fail-and might fail-provides insight into how to redesign them successfully. But today's successful design will be tomorrow's failure, for the expectations of technology are themselves constantly being revised.**

In my essay Art is the Process of Destruction I analyzed the two aspects of being, namely, *process* and *content*. *Content* is basically things you can manipulate and carry, like a bag or a bicycle. Process is some manipulation you do, some action in real-time, in the present. Content is always a thing of the past, many only milliseconds ago, but definitely the past: all things exist in past. Look away from a table and it exists in the past — it might not be there when you look back. *Look* is a *process*. Everything has a *content* and *process*. You can carry a bag (bag as *content*) or you bag some groceries (bag as process). You can carry a bicycle (*content*) or you can us it to bicycle (*process*) to the grocery store. Our language has nouns (*content*) and verbs (*process*). The word verb can be used as content: How many verbs in the previous sentence? The word noun can be used as a verb: Every verb can be *nouned*. As Petroski quotes Epictetus as saying, "Everything has two handles — by one of which it ought to be carried and by the other not." *Content* can be carried, but *process* not, as it does the *carrying*.

When we are talking about something with a visual display on the wall, it is useful to have a pointer to show the person where to look — so you point (*process*) to something when you make a point (*content*). Petroski takes us through the history of pointers, from ten foot tall early pointers, to collapsible metal ones, to laser pointers. Some variations of new pointers worked, others didn't. Those that failed succeeded in prompting a new design.

> **[page 49] Failures are remarkable. The failures always teach us more than the successes about the design of things. And thus the failures often lead to redesigns — to new, improved things. Modern designers and manufacturers can do this on their own, or they can be encouraged to do it by consumers, who essentially are design critics who vote with their purchases.**

This would be a good point for a definition of "failure" and Petroski provides with one:

> **[page 51] "Failure is an unacceptable difference between expected and observed performance," according to the comprehensive definition used by the Technical Council on Forensic Engineering of the American Society of Civil Engineers. Good design is thus proactive failure analysis, something that both a designer and the chooser among designs ought to practice. . . . A warehouse with a door narrower than inventory it was built to store is a decided failure.**

Every large-scale project needs a prototype of some kind. We'll seen architectural models of new buildings, but consider large chemical plants using a new process: a still architectural model offers no insight into whether the process will operate correctly. A smaller scale working chemical plant is built first to verify that the process will actually work to create the chemical products and that is called a prototype. Today designers of novel objects on a small scale have 3-D Printers to test out their designs. Within minutes of completing a design in Autocad, the design can be output to a 3-D Printer which will mold it into a plastic object in its full three dimensional shape. That kind of prototyping provides instant feedback on shape issues. To paraphrase the famous Boston slogan, *Vote often and early for James Michael Curley*, the creed of the successful *failer* is "Fail often and early."

> **[page 64] Prototyping can be viewed as a "sort of three-dimensional sketch-pad," with the prototype enabling potential backers and users to see the invention as a tangible thing. Dennis Boyle, a studio leader at the design firm IDEO, further sees the construction of "rapid and rough prototypes" as a means of identifying problems early in the design process, when they are less costly to correct. According to Boyle, if a "project is not generating masses of prototypes, including many that clearly won't fly, something is seriously wrong." The creed at IDEO is thus "Fail early, fail often."**

How do you react to failure in your own life? This is an important question for you, dear Reader, to ponder. I once met a guy who told prospective employees, "You can hire me — I'm used to being fired." He was a man who learned from his mistakes and wasn't bashful about admitting it. It is never too late to fail at something — *and* to learn an important life's lesson in the process of failing. Learn to fail and learn from failing and you can move from a user of things to a designer of things, from someone life happens to to someone who makes life happen.

> **[page 64, 65] How individuals react to failure separates leaders from followers, true designers from mere users of things. Professor Jack Matson of Pennsylvania State University believes so strongly in the role of failure in design that he expects students in his Innovative Engineering Design course to fail in order to pass. The course, nicknamed "Failure 101," requires students "to build and attempt to sell outlandish and frequently useless products," like a hand-held barbecue pit. The most successful students in the course are those who take the most risks and so fail the most.**

In the 1980s a popular workshop assignment was to solve the "Nine Dots" puzzle. To create a solution, one had to draw the lines outside of the Nine Dots. Nothing prohibited anyone from doing so, but those of us who had solved the puzzle watched as others struggled to find a solution. Somewhere in time, the real lesson to the "Go beyond the nine dots" has been lost, and Matson in the above passage makes it explicit: It is learning to go "beyond the known into the unknown". The known is a map and the unknown is a territory. When we explore the territory and make mistakes, have failures, we update our maps. If we blindly follow our maps, we endanger ourselves when the territory differs from our map. In the Norwegian Boy Scout Handbook the section on map reading contains a sober warning for those scouts who might be exploring regions where steep cliffs drop some thousand feet to icy fjords below : "If the terrain differs from the map, believe the terrain!" Finding a safe ground between going off map for successful failures and remaining in the safe known is the challenge for all explorers, both scouts and designers. We follow Yogi Berra's advice when he said, "I don't want to make the wrong mistake." (Page 91)

> **[page 65] Matson hopes to get them to the point "where students learn to disassociate failures resulting from their attempts to succeed from being failures themselves." He believes that, "Innovation requires that you go beyond the known into the unknown, where there might be trap doors and blind alleys. You've got to map the unknown. You map it by making mistakes." It is not unlike being blindfolded in a labyrinth(4). Smacking into walls may signal a misstep, but the sum of those missteps defines an outline of the maze. The quicker more mistakes are made, the quicker the maze is mapped. Matson is an advocate of "fast failure."**

In this next passage, we learned that the width of the standard gauge railroad was determined by two horses' asses.

> **[page 65,66 *italics added*] Whether fast or slow, failure and its avoidance have always been central to the development of designs and their far-reaching influence. Though often considered apocryphal, the familiar story of the standard railroad gauge of 4 feet 8 ½ inches serves as an example. This odd distance between rails is believed to be rooted in ancient times, when all Roman war chariots came to have that same wheel spacing, which is said to have been established to be no wider than the *rear ends of the two horses* that pulled a chariot. This width, which prevailed throughout the Roman Empire, ensured that the horses would not pull a too-wide wagon through an opening only wide enough for them. As the standardized chariots ranged throughout the empire, they wore deeper and deeper ruts in the Roman roads, including those in England. So, the development of English wagons incorporated the same wheel width, lest their wheels not ride in the ruts, the path of least resistance and least damage — and of least failure. . . . The engineer Robert Stephenson . . . [in 1850] adopted what came to be known as the "standard gauge."**

We have all heard about how the *Titanic* was called the "unsinkable ship" until on its maiden voyage, an iceberg pierced the underwater side of the ship from bow to stern, flooding all the carefully separated compartments which were designed to make the ship unsinkable if one of them were to be pierced. Quickly designed were changed on all future ships to prevent such a catastrophe from recurring.

> **[page 96] Thus, the failure of the *Titanic* contributed much more to the design of safe ocean liners than would have her success. That is the paradox of engineering and design.**

My phrase for this so-called paradox is a caveat: "Remember the pioneers get the arrows!" The more I matured, the more I avoided the latest and greatest innovation, waiting for some time for the new gimmick to prove itself. Don't book a ride on a maiden voyage of a new design, don't buy the latest hybrid auto, the newest recording media, and so on. I recall my buying the earliest LaserVision players and disks. The disks were the size of LP's and gave dependable video and sound, for a time. Within a couple of years, the present DVD designs replaced them and my large disk players were obsolete and disks were useless trash. I learned patience.

There was another failure associated with *Titanic* that Petroski reveals to us, and that failure led to radio broadcasting. The idea of broadcasting is so familiar that it's hard to imagine a world in which this was a foreign or unknown concept. If it had been a common concept at the time of the sinking of the *Titanic*, then hundreds of live could have been saved. The reason the distress calls were not answered by nearby ships was that their wireless sets were only used for expected calls from known sources, so after bedtime the wireless was shut off and unmanned.

> **[page 104] It was not until after World War I that the advantage of broadcasting programs to what came to be called radios was fully realized and exploited.**

In building the first trans-Atlantic undersea cable, Bell Laboratories was charged with deciding whether to use the brand-new, ultra-reliable transistor technology which would last for years, or the old vacuum tube technology which would require lifting the many repeater stations along the cable every six months to replace the vacuum tubes which had burned out. Their analysis showed the clear, expected superiority of the transistor over the vacuum tube. Which one did they recommend? The vacuum tube. Why? Because of one salient point: transistors were projected to have a 25-year lifetime, but no transistor had been existence more than a couple of years! Vacuum tubes, on the contrary, had over 25 years in existence with hard Mean-Time-Between-Failure (MTBF) statistics. Transistors had not been around long enough to have MTBF statistics. On projects too big to fail, hard MTBF statistics are invaluable in making decisions.

> **[page 109] There is another kind of large thing that cannot be readily tested until it is fully built and tried. This is the civil engineering project — the dam, tunnel, building, bridge — whose scale is so large, whose cost is so great, and whose design is so specific to the site that the structure is unique. Because it is one of a kind, not made in a factory but constructed in place, there is no disposable example to test. Scale models may be employed for testing theories or comparing alternative designs, but no model will ever fully replicate conditions of the actual as-built structure. Even if incontrovertibly meaningful models were possible, it is not possible to simulate fully the natural forces of future earthquakes, wind storms, and the like to which the structure might be subjected. In short, the only way to test definitively a large civil engineering structure is to build it in anticipation of how nature will challenge it and then let nature take its course. This fact of large-scale engineering demands careful, proactive failure analyses.**

No doubt such a proactive failure analysis is what Japanese officials are going through after the combination of 8.0 Earthquake, 30 foot high tsunami, and 4 Nuclear Plants's destruction in 2011. What we heard as reasons for the disasters immediately afterward from Japanese engineers sounded like their design was based on a success-based analysis, which, as Petroski has so definitely shown, opens up large scale systems to large scale catastrophes. Reports of up to 50,000 deaths have surfaced in recent weeks. The reactor fuel rods still need to be removed to stop the nuclear reaction which is creating heat which must be removed by improvised cooling systems after the tsunami flooded the back-up generators and destroyed the primary cooling pumps. The Chernobyl nuclear disaster showed the USA's wisdom of insisting on heavily reinforced concrete containment buildings. The Russians had access to the same studies the Americans did, but they saw the probability of a catastrophic failure as too small to justify a containment building, and the Americans saw the same probability as large enough to justify one. Too small and too large decisions are not engineering decisions, but decisions by those contracting for the work. People ask me if America's nuclear plants are safe, and I tell them, so far we've made the right decisions, and quote the containment building decision as an example of a right decision.

Physical proof tests, Petroski says on page 111, "fell out of favor in the United States" in the late twentieth century. We went to computerized simulations to prove the worthiness of a structure. At that time I was working for Lockheed Aircraft Corporation which was building their L-1011 Jumbo Jet airliners to compete with Boeing's 747 and McDonnell-Douglas DC-10. At the same time, the DC-10 was being tested via computer simulations, Lockheed had built an entire L-1011 in their Palmdale manufacturing facility which was undergoing a proof test of its projected 20-year flying life by means of hydraulic arms moving the plane's wings up and down for the number of hours the plane would fly in the course of 20 years. Both methods proved to be equally effective, but one can see the concern that Lockheed had: to ensure no plane of its would ever fall apart.

Petroski points out that a proof test of the NYC twin towers was virtually impossible in the 1960s because the conditions existing during their collapse in 2001 had not been created. A full-fueled Boeing 767 flying at unreasonably high speeds could not have been envisioned fifty years earlier.

> **[page 112] Like any scientific hypothesis, [a proof test of the towers] can never be proved to the extent that a mathematical theorem can be; but it can be disproven ("falsified" in the language of Karl Popper) by a single counterexample. In the engineering of large and small structures alike, that counterexample takes the form of an unambiguous failure.**
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> **Failure, not success, then, is the true touchstone of design. It would have been virtually impossible to have devised a proof test of the twin towers of the New York World Trade Center to withstand the combination of physical assault on its structure and the conflagration that ensued on September 11,2001. That is not to say that structural engineers did not consider the possibility of an airplane crashing into the tall buildings. After all, a B-25 bomber did fly into the Empire State Building in 1945. Structural analysis of the effects of an impact of a Boeing 707, the largest airliner flying at the time, was carried out while the twin towers were being designed, and it was concluded that the structure could take such an insult without collapse. In 2001, of course, Boeing 767s were deliberately crashed into the towers, which clearly initially were able to take the considerable structural damage that was inflicted upon them. This confirmed their mechanical robustness, but not their ability to withstand what followed.**

This is theme of Petroski's book on the paradox of design, "Things that succeed teach us little beyond the fact that they have been successful; things that fail provide incontrovertible evidence that the limits of design have been exceeded. Emulating success risks failure; studying failure increases our chance of success." The best designs according to Petroski are those based not on the best and most complete assumptions of the successes of previous designs, but rather based on the best and most complete assumption about the failure of the present design under consideration. Only then can we achieve "Success through Failure."

---------------------------- ***Footnotes*** ---

Footnote 1. ROTC is an acronym for the *Reserve Officers Training Corps*, two years of which was required of all male US students enrolled in Land Grant Colleges such as LSU. The requirement has since gone, but Army (as I was in) and Air ROTC continues on many campuses into the twenty-first century. Plus many Junior ROTC units in High Schools.

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Footnote 2. This reminds me of the many PowerPoint Presentations that I have been forced to attend which were like shadows of the real world thrown upon the wall of the classroom or auditorium, perhaps useful maps of the territory outside, but still only maps. Petroski describes the similarity in detail on page 13.

Return to text directly before Footnote 2.

Footnote 3. I was surprised to discover that 35 mm color slides appeared in the mid-1930s because I recall looking at some color slides of a family at a swimming pool at my grandmother's house in the early 1940s, less than a decade after the invention. For several decades it was the only color photos which were available at an affordable price. By the time I took a motorcycle ride to Yellowstone in 1979, it was already difficult to find Kodachrome slide film.

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Footnote 4. In her book, "Reality Is Broken" Jane McGonigal discusses a game which in which blindfolded players negotiate a labyrinth. The game is described here: http://olympics.wikibruce.com/The_Game

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