The Evolution of Artifacts

Henry Petroski

In the beginning of his important book, *The Evolution of Technology*, George Basalla notes that the diversity of natural things has intrigued people for centuries. Biologists, he observes, have identified and named more than 1.5 million species of flora and fauna. The diversity of things made by human hands is also very great, but Basalla points out that this diversity is harder to quantify, since "distinct species cannot be identified with any precision among items of human manufacture." He does offer one rough measure: the number of patents granted. If each of the roughly 5 million patents that have been issued in the United States alone is counted as the equivalent of an organic species, he says, the diversity of technology can be considered to be three times as great as that of the natural world. Recognizing the difficulties of comparing apples and orange peelers, Basalla concludes conservatively that "the diversity of the technological realm approaches that of the organic realm."

But quantifying diversity among artifacts only makes more vexing other fundamental questions. How do we account for technological diversity? What is the mechanism by which artifacts multiply? Basalla does not believe that necessity and utility alone can account for the great variety and novelty of made things. Heedful of E. E. Cummings's observation that "A world of made is not a world of born," he recognizes that we should not expect a one-to-one correspondence between a purposeful human activity and a random natural process. So Basalla pursues the evolutionary analogy selectively. The pursuit does indeed pay off in a rich and rewarding book full of fresh insights into questions of continuity and discontinuity, novelty and selection in technology. Examples abound in Basalla's work, with artifacts as diverse as barbed wire, the automobile and the transistor providing case studies to support his arguments.

Patents play a merely quantitative role in Basalla's book; yet the patent literature can provide much more than mere numbers, for it is an excellent source of material for pursuing the question of technological evolution on its own terms. Indeed, patents might be considered almost primary sources for understanding the principles behind invention itself: In many cases they give us the story straight from the inventor's mouth, albeit in a formal context. And even when patent attorneys or agents serve as amanuenses of sorts, each patent document is still putting forth a direct and explicit case for a new species of artifact. Certainly, then, these documents must contain at least some clues as to how technology evolves.

The experience of picking up and reading any of the millions of patents issued in this country over the past two centuries is almost certain to reinforce the conventional wisdom that technology is boring stuff indeed, and that those who work in the world of things do not express themselves easily in words. In spite of the fact that these documents are supposed to convey the essence of an invention to those "practiced in the art," the literary style of patents (if that is not an oxymoron) leaves much to be desired. The text of a patent is invariably repetitive, redundant, diffuse and, above all, prolix. Surprisingly, considering that its protection is granted in exchange for a revelation of new technology, a patent can be in some places as annoyingly vague as it is elsewhere maddeningly precise. When a patent is illustrated, the accompanying text may or may not support the saw that a picture is worth a thousand words, but the converse is not uncommonly true: A patent may take more than a thousand words to give little more than a line-by-line description of what appear to be the interminably numbered details of the drawings.

For all their shortcomings as examples of technical writing, however, patents do have a structure and do follow a form—one that today is largely imposed by tradition and by the expectation of patent examiners that they will find certain elements in certain places in the patent application, as the written document submitted to them is officially known. A patent tends to follow rather closely the form extant within the class of existing patents with which the applicant wishes the invention to compete. Thus, for example, paperclip patents dating from the early years of this century invariably begin with the salutation, "To all whom it may concern," and proceed with minor variations on the opening, "Be it known that I... have invented certain new and useful improvements in Paper Clips..., of which the following is a specification." By the 1930s, the language had been modernized and streamlined, and we find more abrupt openings, such as, "This invention relates to improvements in paper clips..." The key word, "improvement," remains and provides the central evidence of purposefulness in technological evolution.

One patent attorney's advice to the do-it-yourself patent seeker provides a means for understanding technological diversity and evolution. The advice is in the form of an inventor's commandment: "In your patent application, you should 'sell' your invention to the examiner or anyone else who may read the application by (a) listing all the disad-

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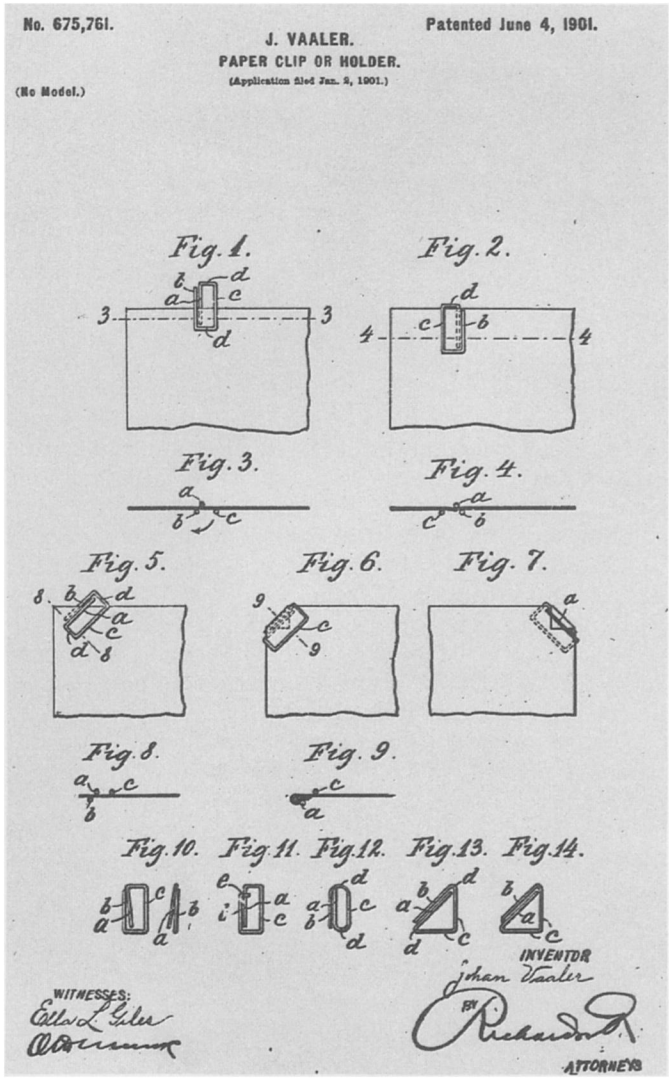

Figure 1. Johan Vaaler's 1901 paper-clip patent (U.S. Patent No. 675,761).

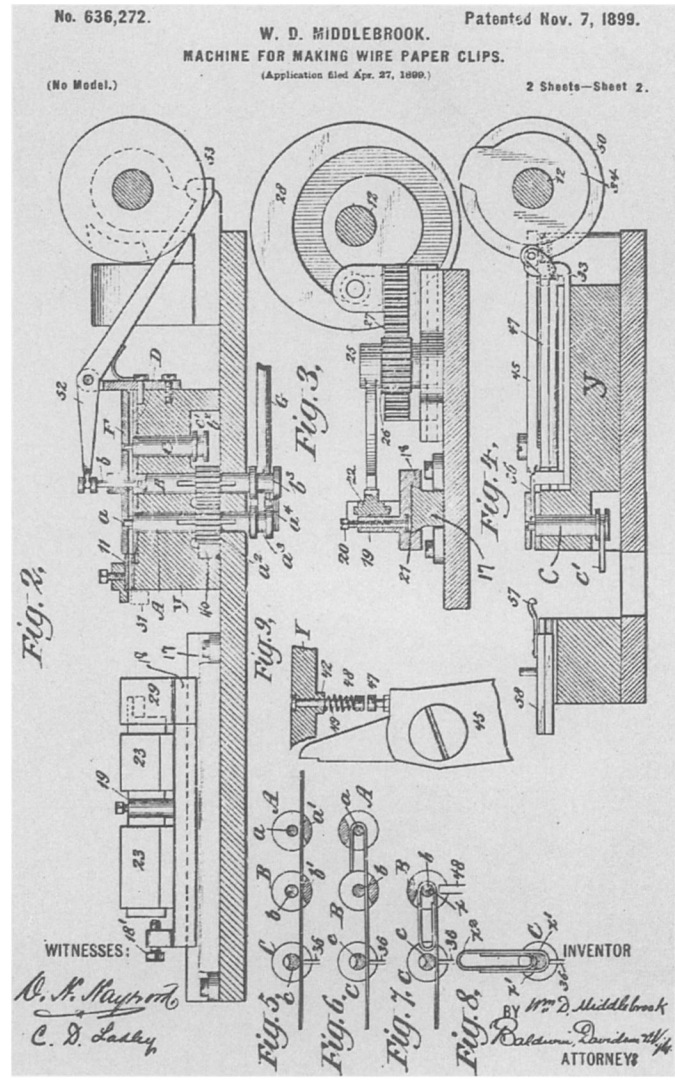

Figure 2. William Middlebrook's 1899 patent (No. 636,272) for a machine for making wire paper clips. A fully formed Gem clip is at lower right.

vantages of the prior art, and (b) all the advantages of your invention, both in the introduction and in a conclusion." Finding fault with the prior art and removing the objection (up to a point) is in fact the key to artifact succession.

The concept of improvement is central to invention—to the evolution of artifacts—and to the institutionalized recognition of success through the patent system. Many patents point out quite explicitly one or more failings of existing devices to accomplish an objective, and the fault-finding is quite conscious. An article entitled "Patent It Yourself" appeared in a recent issue of *Design News*. Included in the advice of its author, a professional engineer registered to practice before the U.S. Patent and Trademark Office, is an exhortation that the writer "explain all the disadvantages and shortcomings of existing and related products," and, in summarizing the invention, begin with, "To avoid the limitations and problems with present (devices/methods)..." Another do-it-yourself book considers it essential that a patent application answer the question, "Why is what the world has not good enough, and how is your invention going to make it better?"

If it is true that fault-finding is the central idea that drives invention, and thereby technological evolution, then tracing the development of any class of artifacts should provide confirmatory evidence. One case study must be as good as any other to test the hypothesis, and the simpler the object, the more clearly might the case be made. After the essential features of the argument are clear, more and more complex examples can provide further case studies and further tests. Naturally, it only takes a single counterexample, whether simple or complex, to disprove the hypothesis that fault-finding drives technological change.

Poking Fun at the Pin

The artifactual antecedent of the paper clip was the straight pin, which has not yet been completely displaced by the clip. As a director of graduate studies five years ago, I received not a few inquiries from Indian students who employed a pin as a paper fastener. Even in this country, the "bank pin" or "desk pin" (identical in every way but its packaging to the "toilet pin," used for fastening garments and in sewing) was in use well into the present century, as I observed recently while examining the archives of a family pencil business. But the pin has some distinct shortcomings in fastening papers. Only a few papers can be fastened; it takes time to thread the pin through the papers; holes are

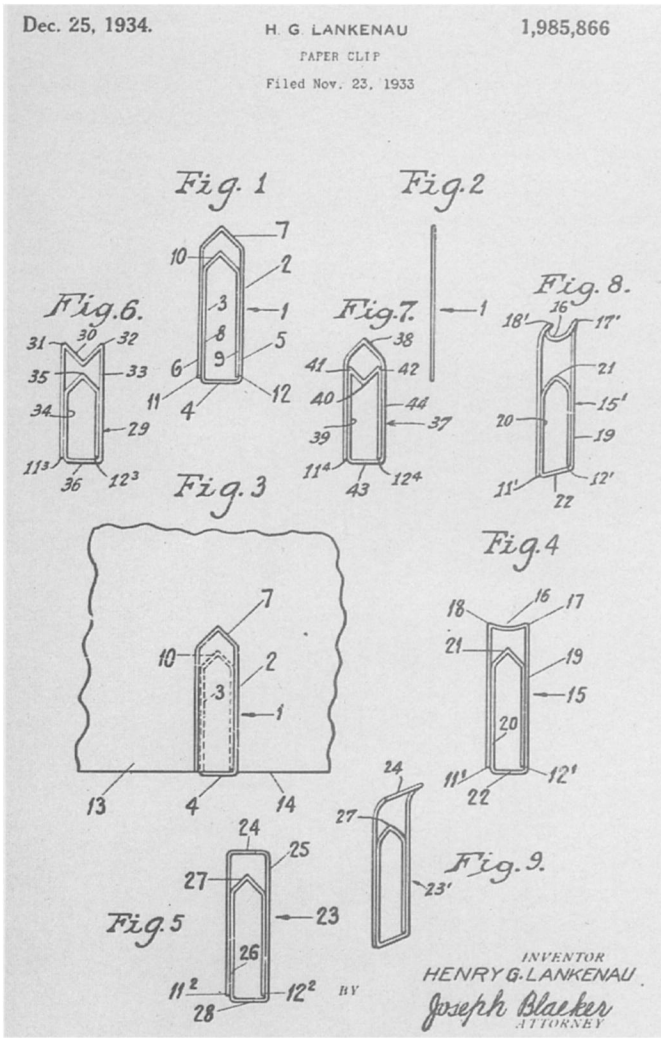

Figure 3. Henry Lankenau's 1934 patent (No. 1,985,866) for a Gothic paper clip.

made in the papers; extraneous papers are snagged by the pin point; fingers are pricked; and so forth. In short, it was easy to find fault with pins as paper fasteners, but until the end of the 19th century there were no readily available and inexpensive substitutes.

Since the faults of the pin were so obvious, it is not surprising that people improvised and inventors tried to come up with better paper fasteners. Basalla has pointed out that clothespins were used by the essayist and historian Thomas Carlyle, and a portrait of the engineer Isambard Kingdom Brunel shows that large, handsome bentwood devices served as paper clips in the mid-19th century. It was also around that time that a great variety of paper fastening devices began to be patented: large and bulky ones resembling the business end of a modern clipboard, and smaller ones of various shapes, generally stamped out of ductile metal. Some of the latter were meant to be folded over the papers, with a protected point that pricked the papers but not the fingers.

As is often the case in technological development, progress was incremental. Old shortcomings that remained or fresh ones that appeared in the newer devices provided the objections to be overcome in further developments of a small paper clip. In 1887 a patent for "improvements in paper fasteners" was issued to Ethelbert Middleton of Philadelphia for devices that he declared secured a "mass of papers without any puncturing or cutting." But attaching Middleton's fasteners was no trivial task, for it involved the almost oragami-like action of folding various metal wings over the corners of the papers to secure them. His clip, like all its predecessors (and descendants), left something to be desired. But this is not to say that there was any absolute need for a better way to fasten papers together.

As steel wire became readily available in the latter part of the 19th century, and as machinery was developed to bend it into a variety of shapes, what we now know as a paper clip evolved. The modern paper clip has the obvious advantages over its antecedents of not piercing the papers it holds and yet being relatively easy to attach and detach. But there are countless ways of bending a piece of wire to hold papers, and inventors around the turn of the century had a field day pointing out in their patent applications the relative advantages and disadvantages of different style clips, most of which have long since become extinct but some of which we use with abandon today.

The modern paper clip is commonly said (in encyclopedias, for example) to have been invented in 1899 by a Norwegian named Johan Vaaler. According to the standard story, since Norway had no patent law at the time, the inventor sought a patent in Germany. He was also granted a U.S. patent in 1901 for "improvements in paper clips or holders," but none of the variations of clips illustrated in this patent resembles what we recognize today as a standard paper clip. Indeed, Vaaler's clips, like many patented around the turn of the century, appeared to be distinguished mainly by their various shapes—rectangular, oval, triangular. Although Vaaler's patent application noted that the clips could be made so that the ends of the wire lay close to each other "to obviate the clips hanging together when being packed up in boxes or the like" (a common fault of some other clip designs), he did not call attention to the fact that his clips would not be easy to attach to papers. More significantly, however, the easy-to-apply clip that we now use predated Vaaler's U.S. patent by at least two years.

The Gem: Form, Function and Flaws

The paper-clip design that we recognize as standard today became known around the turn of the century as the Gem, presumably after the British manufacturer Gem, Limited, but the design itself seems never to have been patented. An unmistakable Gem-style paper clip appears to have been familiar enough to have been used only incidentally and without particular comment among the figures of a patent issued in 1899 to William Middlebrook of Waterbury, Connecticut, for a "machine for making wire paper clips." What is clearly a Gem is described only as "of the general shape and character illustrated." Even if the Gem paper clip did not exist outside Middlebrook's patent application for his machinery, the "publication" of the paper-clip design in this context would have precluded the Gem itself from being patented subsequently.

Regardless of how it was introduced, and whether first in America or in Norway, the Gem had considerable advantages over older paper fasteners and even over newer ones such as the variations in Vaaler's patent. But no artifact is perfect, and the Gem had (and still has) its own faults and flaws. It takes a bit of maneuvering to apply to papers; its wire ends can snag stray papers; it can tear papers when being removed; it can only hold so many papers. Insignificant as they may seem to most of us, such failures of the Gem

(and every other paper-clip design) to be all things to all papers offered all that inventors needed to seek improvements, and the patent files record the various evolutionary paths that the paper clip followed from the Gem and related designs in the early 20th century.

Two common problems with paper clips remained their tendencies to entangle in the box and then, in use, to move about and work loose as piles of papers are shuffled. Cornelius Brosnan of Springfield, Massachusetts, was one of many inventors to address such details, and a patent was issued to him in 1905 for a paper clip "of novel shape" that looked like an arrowhead. Brosnan's patent states that this clip could be applied with ease (implying, of course, that others could not) and "with certainty of its being maintained when in its binding engagement without liability of swinging or shifting" (as others were known to do) and would "not become interlocked one with another to cause bother and delay in taking one or more out from the box" (as inferior clips did). But ease of application, for example, is a relative thing, and inventors continued to seek alternative means of removing that shortcoming and others. As late as 1920, Joseph O'Brien, also of Springfield, patented a variation on the Gem, with "the terminal of the inner loop being extended cross-wise to provide a thumb engageable bar, whereby the two loops or jaws may be separated to facilitate ready insertion of paper between the jaws." In that same year, Harry Baldwin of Seymour, Connecticut, patented a variation on the arrowhead shape that had more crossings of the wire, which he argued gave his clip "a larger number of bearing or gripping points than as heretofore constructed and which will therefore securely hold the papers in position," thus overcoming the faults of clips that slipped.

By the 1930s the Gem design was so firmly established as the standard that Henry Lankenau of Verona, New Jersey, attacked it by name in his 1934 patent for a paper clip that had V-shaped loops on one end, in place of the familiar U-shaped ones. According to the patent, the pointed geometry of the new clip provided "a wedge action" and could be "more easily applied to two or more papers than the type of clip generally known in the art as 'Gem' clips." Furthermore, because the wire ends or legs of Lankenau's clip extend to its squared other end, they "cannot dig in and scratch the paper as is usually the case when removing paper clips of the 'Gem' type having short legs which do not extend to the extreme end of the clip." While sometimes called a "perfect Gem," Lankenau's angular design has come to known more generally as a Gothic clip, in contrast to the Romanesque Gem, and it has a small but fervent following to this day. Duke's library, for example, uses such clips, and I have come to find them superior to the Gem in many ways.

The Gem, for all its (minor?) faults, has evolved to be the standard paper clip, and it is important to understand why this is so. The internal evidence of the patent record clearly documents how competing artifacts are explicitly pitted against each other with regard to their relative strengths and weaknesses. (The name-calling started in the patent application is, of course, carried on with varying degrees of explicitness in the marketplace.) Since every artifact, even something so seemingly simple as a paper clip, has numerous competing objectives and criteria against which it is judged, it is not to be expected that any given device will come out on top in every single category. Different users have different priorities and place different emphases on the various faults and failings of the artifacts among which a choice must be made. A library, for example, might be willing to pay more for clips that do not tear books. An accounting office, on the other hand, might care less about scratching or tearing little nicks out of the tops of checks in the interest of processing them quickly. In the final analysis, such diversity among users leads to diversity among artifacts.

The current catalogue of Noesting, Inc., which claims to have carried the world's largest selection of paper clips for over 75 years, offers more than a dozen different clips in various sizes. The company even still sells the paper clip's precursor, the pin: the "economical fastening device used when papers must be fastened more securely than clips can and taken apart later without the mutilation of staples, used with securities and tissue-thin receipts." Thus the century-old quest for improvements on this basic artifact has still not displaced it completely. Not that inventors haven't tried, of course. As late as the 1960s, Howard Sufrin, collector of antique office products and heir to the family business that made Steel City Gems, could state, "We average ten letters a month from people who think they have an improvement."

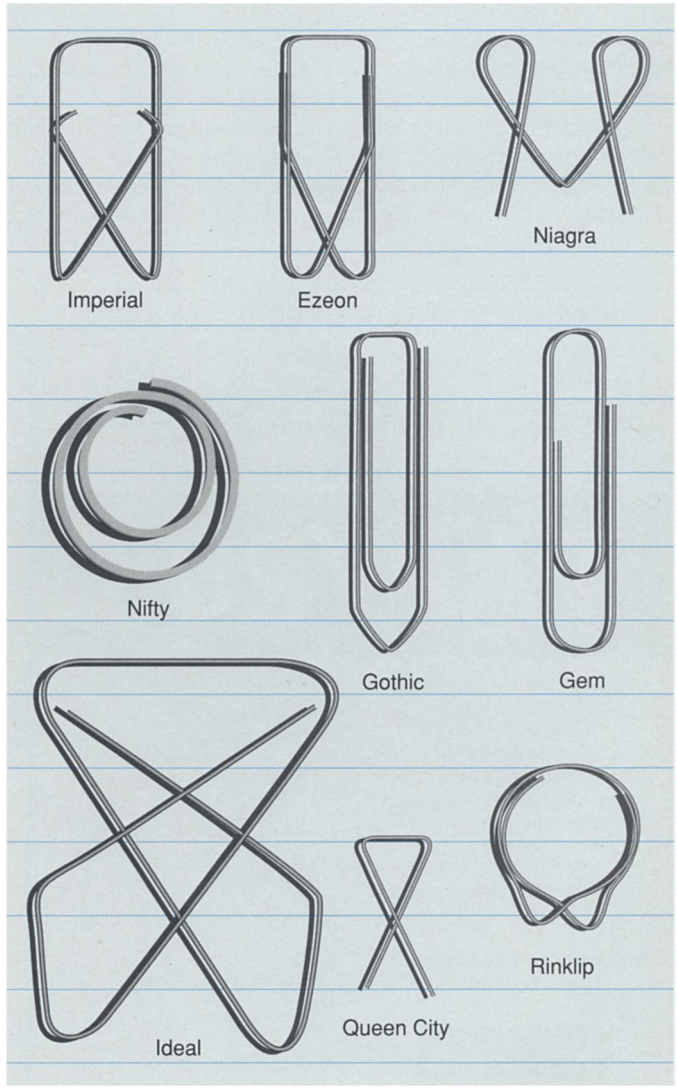

Figure 4. This sampling of paper clips that have been introduced over the years provides a collection of incontrovertible counterexamples to the design dictum that "form follows function." Each new paper-clip design, whether patented or not, addressed at least one shortcoming of existing designs.

Purely functional reasons naturally are not the only ones for establishing diversity and dominance among artifacts. Economic factors are extremely important in shaping the made world, and patent after patent includes phrases like "simple construction" and "cheapness of construction." All other things being equal, the "cheaper" artifact should drive out the more expensive (except, for example, where the lack of snob appeal is perceived as a fault). However, while "cheapness" can sometimes be achieved by a more efficient manufacturing process or more economical arrangement of parts, more commonly it is achieved at the expense of other qualities, for invention and engineering are first and foremost arts of compromise. A cheaper paper clip can easily be achieved by reducing the thickness of wire, but this will typically mean that the clip has less spring, less holding power or less durability. Many recently introduced plastic versions of paper clips may be very colorful, but they seldom work like a Gem.

Aesthetic factors can play an extremely significant but hard-to-quantify role in the evolution of a dominant form of an artifact. Designers and design critics frequently name the (generic) paper clip, which invariably they take to be synonymous with the Gem, as an example of a brilliant solution to a design problem. Owen Edwards's description in his book, *Elegant Solutions*, is typical: "In our vast catalog of material innovation, no more perfectly conceived object exists.... With its bravura loop-within-a-loop design, the clip corrals the most chaotic paper simply by obeying Hooke's law." The architecture critic Paul Goldberg has also sung the praises of the (unnamed) Gem: "Could there possibly be anything better than a paper clip to do the job that a paper clip does? The common paper clip is light, inexpensive, strong, easy to use, and quite good-looking. There is a neatness of line to it that could not violate the ethos of any purist. One could not really improve on the paper clip, and the innumerable attempts to try—such as... clips with square instead of rounded ends—only underscore the quality of real things." One could hardly ask for sharper statements pointing out the existence of two cultures—critics whose medium is words and critics who medium is matter—when it comes to understanding the evolution of artifacts and technology generally. Ironically, those most commonly associated with aesthetic judgement appear to be more easily satisfied with form (and function) than those who shape the artifacts being criticized. Yet again and again in their patents, the collective voices of the evolvers of technology echo to a fault the observation of one of their greatest, Henry Bessemer: "The love of improvement... knows no bounds or finality."

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