From: George Basalla. 1988
The Evolution of Technology

CHAPTER II

Continuity and Discontinuity

Introduction

A large segment of the modern public believes that technological change is discontinuous and depends on the heroic labors of individual geniuses, such as Eli Whitney, Thomas A. Edison, Henry Ford, and Wilbur and Orville Wright, who single-handedly invent the unique machines and devices that constitute modern technology. According to this view inventions are the products of superior persons who owe little or nothing to the past.

The smaller scholarly community that concerns itself with issues in the history of technology and science rejects this explanation as simplistic because it reduces complex technological developments to a series of great inventions that precipitately burst upon the scene. However, some historians have offered more sophisticated formulations of the discontinuous explanation that do not rely upon the contributions of heroic inventors. Such theorists take their cue from the supposed revolutionary nature of scientific change.

Science, Technology, and Revolution

Recent scholarship in the history and philosophy of science has tended to favor the discrete character of scientific change. This outlook derives ultimately from the study of the emergence of modern science in the sixteenth and seventeenth centuries. Since the French Revolution, the work of Copernicus, Galileo, Kepler, and Newton has been described by the term *revolution*, a political metaphor that implies a violent break with the past and the establishment of a new order.

The political metaphor was applied not only to the arrival of a

new way of studying nature but also to any substantial change within a science. Hence, reference is made to the astronomical, chemical and biological revolutions of the past; to revolutions initiated byHarvey, Bacon, Darwin, Mendel, or Einstein; or to twentieth-century revolutions in quantum physics, astrophysics, and molecular biology.

Scientific revolutions take on a special importance for the study of technological change when technology is placed in a subordinate position to science. This situation usually occurs when technology is erroneously defined as the application of scientific theory to the solution of practical problems. For, if technology is nothing more than another name for applied science, and if science changes by revolutionary means, then technological change too must be discontinuous. tool

Of course, science and technology have interacted at many points, and key modern artifacts could not have been produced without the theoretical understanding of natural materials and forces provided by science. Nevertheless, technology is not the servant of science.

Technology is as old as humankind. It existed long before scientists began gathering the knowledge that could be used in shaping and controlling nature. Stone-tool manufacture, one of the earliest known technologies, flourished for over two million years before the advent of mineralogy or geology. The makers of stone knives and axes were successful because experience had taught them that certain materials and techniques yielded acceptable results, whereas others did not. When a transition was made from stone to metal (the earliest evidence for metal working has been dated ca. 6000 B.C.), the early metal workers, in a similar fashion, followed empirically derived recipes that gave them the copper or bronze they sought. Not until the late eighteenth century was it possible to explain simple metallurgical processes in chemical terms, and even now there remain procedures in modern metal production whose exact chemical basis is unknown.

In addition to being older than science, technology, unaided by science, is capable of creating elaborate structures and devices. How else can we account for the monumental architecture of antiquity or the cathedrals and mechanical technology (windmills, waterwheels, clocks) of the Middle Ages? How else can we explain the many brilliant achievements of ancient Chinese technology?

The arrival of modern science did not put an end to endeavors that were primarily technological; people continued to produce technological triumphs that did not draw upon theoretical knowledge. Many of the machines invented during Great Britain's Industrial

Revolution had little to do with the science of the day. The textile industry, at the heart of eighteenth-century economic growth, was not the result of the application of scientific theory. The inventions of John Kay, Richard Arkwright, James Hargreaves, and Samuel Crompton, which were crucial to increased textile production, owed more to past craft practices than they did to science.

Only during the latter half of the nineteenth century did science begin to have a substantial influence on industry. Developments in organic chemistry made possible the establishment of large-scale synthetic dye production, and the study of the nature of electricity and magnetism laid the foundations for the electrical light, power, and transport industries. The twentieth century witnessed the further expansion of science-based technologies. Despite the influx of new scientific theories and data, modern technology involves far more than the routine application of the discoveries made by scientists. In modern industry science and technology are equal partners, each making its unique contributions to the success of the enterprise in which they are engaged. Even today, however, it is by no means exceptional for an engineer to devise a technological solution that defies current scientific understanding or for engineering activity to open up new avenues for scientific research.

The issue of discontinuous change within technology was revived by Edward W. Constant in *The Origins of the Turbojet Revolution* (1980). Drawing upon Thomas S. Kuhn's *The Structure of Scientific Revolutions* (1962), Constant argues that a discontinuity existed between turbojet engines, the major aircraft power source since World War II, and the older propeller–piston engines (Figure II.1). The turbojet, which has neither piston, nor cylinder, nor propeller, was not the evolutionary outcome of the continuous improvement of the propeller–piston engine.

Constant believes that the turbojet revolution deserves its name because the turbojet is a holistic system that has technological antecedents but differs from them radically; the design of the turbojet, and its incorporation into aircraft, called for the application of advanced scientific theories in aerodynamics; and the turbojet was created by a small group of men who were not part of the conventional aeroengine community. Of all of these factors, Constant stresses the importance of the emergence of a new community of technological practitioners associated with the turbojet. This new community was identical with neither the conventional aeroengine community nor the older community of steam- and water-turbine technologists. In Constant's terms, technological revolution becomes "the professional commitment of either a newly emerging community or redefined community to a new technological tradition."[1]

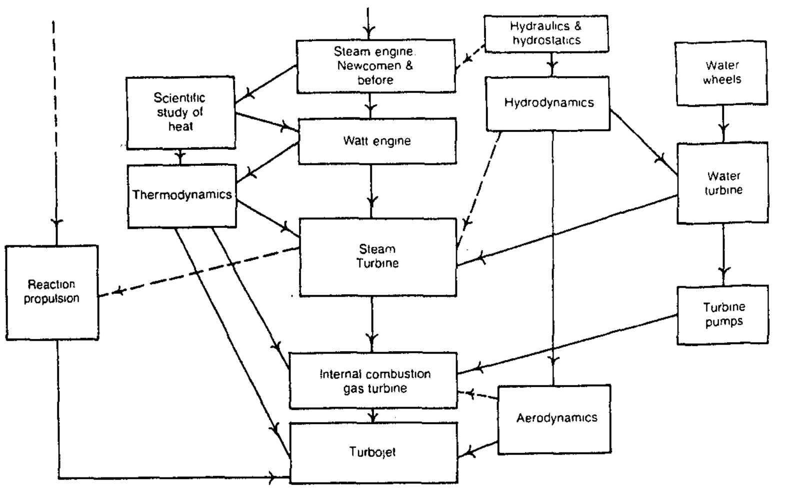

Figure II.1. E. W. Constant's diagram illustrating the relationship between artifact and theory in the lineage of the turbojet engine. The main artifactual stream, depicted in the center, moves from steam engines, to steam and internal combustion gas turbines, to the turbojet. On the far right water turbines and turbine pumps are linked to this main stream, and in the columns immediately adjoining the center the influence of relevant physical theories is indicated. Remember that these theoretical contributions manifest themselves in the form of some novel tangible thing whose antecedents predate the theory. Despite the existence of this artifactual network, Constant remained convinced that the turbojet was a revolutionary advance and not an evolutionary one. Source: Edward W. Constant II, *The origins of the turbojet revolution* (Baltimore, 1980), p. 4.

Two crucial assumptions underlie Constant's explanation: that technology is primarily knowledge; and that the community of technological practitioners is the fundamental unit to be studied in technological change. These assumptions deserve exploration.

Despite its seemingly revolutionary character the turbojet engine was not a machine without antecedents. The turbojet belongs to the two-hundred-year-old tradition of turbine development that encompasses water turbines, turbine water pumps, steam turbines, internal combustion gas turbines, piston engine superchargers, and turbosuperchargers. None of these has pistons and cylinders but they all have a turbine wheel with fins or buckets that, when acted upon by water, steam, or hot gases cause the wheel to rotate rapidly. Therefore, at the level of the artifact, two centuries of continuity has prevailed in the family of turbines, whatever their varied uses or energy sources.

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The artifact – not scientific knowledge, nor the technical community, nor social and economic factors – is central to technology and technological change. Although science and technology both involve cognitive processes, their end results are not the same. The final product of innovative scientific activity is most likely a written statement, the scientific paper, announcing an experimental finding or a new theoretical position. By contrast, the final product of innovative technological activity is typically an addition to the made world: a stone hammer, a clock, an electric motor.

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Historian Brooke Hindle has claimed that the artifact in technology occupies a position superior to that held by artifacts in science, religion, politics, or any of the intellectual or social pursuits. At every point technology is intimately involved with the physical, with the material; artifacts are both the means and the ends of technology. The three-dimensional physical object is as much an expression of technology as a painting or a piece of sculpture is an expression of the visual arts. The artifact is a product of the human intellect and imagination and, as with any work of art, can never be adequately replaced by a verbal description.

therefore technology is not primarily knowledge

The centrality of the artifact for an understanding of technology is a key element of the evolutionary theory being developed here. In this chapter, as well as the rest of the book, the artifact is the primary unit for study. Artifacts are as important to technological evolution as plants and animals are to organic evolution.

Case Studies in Continuity

Given the primacy of the artifact in the study of technology, the continuous nature of technological change can best be established by using case studies to show precisely how key artifacts – such as the steam engine, the cotton gin, or the transistor – emerged in an evolutionary fashion from their antecedents. The following examples of artifactual change illustrate the evolutionary hypothesis despite the fact that initially they appear to be excellent candidates for use in supporting the contrary discontinuous explanation.

Stone Tools

The oldest surviving made things are stone tools. They stand at the beginning of the interconnected, branching, continuous series of artifacts shaped by deliberate human effort. Individual branches of the series may have stopped at cul-de-sacs but the wider stream of made things has never been broken. The modern technological

world in all of its complexity is merely the latest manifestation of a continuum that extends back to the dawn of humankind and to the first shaped artifacts. Stone implements may not offer a crucial test for the evolutionary thesis, but they provide the best illustration of continuity operating over an extended period of time.

For at least two million years men and women in all parts of the earth made stone tools, hundreds of billions of them. These tools constitute the most ancient, widespread, and numerous artifacts in existence today. For most of the time tools were made by chipping and flaking techniques that when carried out by skilled workers, yielded a serviceable instrument within a relatively short time – a matter of minutes or hours. Axes, adzes, hammers, knives, and scrapers of all sorts were produced by these means. The Neolithic period, which began some eight thousand years ago, witnessed the introduction of agriculture, domestication of animals, and pottery, as well as polished stone tools made by the laborious process of pecking and grinding the stone to the desired shape and finish. Grinding, especially, required days or weeks of work; however, it resulted in tools well suited for prolonged hammering and chopping.

Whatever the technique employed, the form of stone tools changed very slowly over the long period of their use. Since the mid-nineteenth century, a number of archaeologists have patiently and ingeniously identified and dated implements that, to untrained eyes, seemed to be similar in shape, size, and material. Once this archaeological evidence was reassembled in chronological order, its most striking feature was the perfect continuity that was maintained for hundreds of thousands of years as wave after wave of different human cultures engaged in stone-tool making.

In the study of stone tools we search in vain for discontinuous jumps to wholly new forms.*The long-lasting shapes of these artifacts even persisted as people made the radical shift from stone to copper and bronze. Traditionally, stone has been associated with primitivism, metal with civilization.*As a material for making tools, stone does have weaknesses. Although it is easily obtained and worked, stone is less durable than metal and less readily shaped. The form of a stone tool is more closely determined by the nature of its material than is the form of a metal tool. The latter can be cast into almost any shape called for by the task at hand. The metal tool is less brittle, therefore, less likely to break. If it does break or show wear, it can be melted down and recast.

Someone unfamiliar with the subsequent history of tools might conclude from this comparison that the appearance of metal ushered in a new era in tool making. But, on the contrary, continuity prevailed. The earliest metal tools had as their closest antecedents stone prototypes. Eventually new metal tools did emerge, but the weight of the tradition of stone technology exerted a long-lasting influence on the shape of these tools. That influence is evident in the form of familiar modern tools, such as the axe, hammer, and saw, and is also apparent in electric and pneumatic tools, which preserve the principles and movements of early stone implements.

This example of continuity is dramatic yet it is open to criticism. Someone could argue that these stone tools owe their remarkable stability to the fact that at an early stage in their evolution they acquired the best possible form for the function they were to perform and hence did not change. Even if this were not true, one could make a case for excluding stone tools from this list of illustrative case studies on the basis that they represent an anomaly because they are so ancient and simple. For critics who would take exception to stone tools, I will present more persuasive tests of continuity in technology that utilize relatively complex machines, created by famous inventors in modern times, rather than artifacts fashioned anonymously in the prehistoric era.

The Cotton Gin

An investigation into the continuous development of a complex machine can profitably begin with Eli Whitney's cotton gin. Although many authors have written about Whitney and his revolutionary invention, far fewer have ventured to place his cotton gin within a continuous stream of artifacts.

According to the popular histories of invention, Whitney, a young New Englander with great mechanical talents, first encountered cotton and its processing problems while on a trip to a Georgia plantation in 1793. The source of the problems, short staple or Inland cotton, could be grown in most of the South but its fibers clung tightly to its green seed making it difficult to clean. A slave spent at least three hours cleaning one pound of cotton by tedious hand labor. Shortly after his arrival in Georgia, Whitney began working on a means to speed up the process. Having observed slaves manually separating fiber from seed, he visualized a machine that could duplicate the motions of their hands. Within a few days he had built a model of the gin that was to change cotton growing in the South forever.

Only the more scholarly studies of Whitney mention the fact that mechanical cotton gins were already in wide use in the South at the time of Whitney's visit. Such engines were capable of cleaning the long staple, or Sea Island, cotton, a plant with a limited growing range but with a fiber easily removed from its black seed. Because of the existence of these gins, it was unnecessary for the inventor to bridge the great gulf between the organic – fingers tugging to free stubborn fibers from seed – and the mechanical. That step had been accomplished much earlier in India where the first cotton cloth was produced centuries before the Christian era.

The Indian gin or *charka*, based on the roller principle, was itself a variant of a still older sugar cane press. The *charka* consists of a pair of long wooden cylinders set in a frame, pressed together, and rotated about the longitudinal axis by a crank. The rotating cylinders, which are fluted with a series of fine, lengthwise grooves, separate seed from fiber by squeezing the cotton boll as it passes between them.

This primitive gin was used wherever long staple cotton was grown and processed. By the early twelfth century the machine was known to Italian artisans as the *manganello*; it appeared in a Chinese illustration of the fourteenth century; and in the eighteenth century it was depicted in Diderot's *Encyclopédie*. In 1725 the roller gin was introduced into the Louisiana region from the Levant and by 1793 it was established in the cotton-growing South where Eli Whitney met it.

Whitney's challenge was to make a gin that would clean short staple cotton. His invention consisted of a rotating wooden cylinder into which were set regularly spaced rows of bent wire teeth whose shape is similar to the wire teeth used in various wool-carding devices. The teeth in Whitney's gin passed through a slotted metal breastwork with openings just wide enough to admit them and cotton fiber but not the cotton seed. Thus the seeds were trapped beneath the breastwork while the fibers were pulled upward and free. The cleaned cotton was then brushed from the teeth by the second rotating cylinder, which had rows of bristles. Like the centuries-old roller gin, Whitney's gin relied on a set of rotating cylinders. Unlike the older gin, Whitney's had a slotted plate (breastwork) to immobilize the seeds while they were being stripped of fiber.

This excursion into ancient cotton processing technology is not meant to prove that inventions are inevitable, or that the modern cotton gin was first constructed by some Indian artisans, or that Eli Whitney was less clever than we have been led to suppose. Whitney's gin cleaned short staple cotton, something the ancient roller gins could not do. Acknowledging the *charka*, however, shows that Eli Whitney's invention had artifactual antecedents whose overall structure and mechanical elements were adapted by the American inventor to suit his purposes (Figure II.2).

Not everyone who looked at the old roller gins visualized how to transform them into a machine capable of handling short staple cotton; some individuals had attempted to adapt the *charka* to processing Inland cotton before Whitney traveled South, but none met with success. Whitney's invention not only succeeded where others had failed but also served as the point of origin for an entirely new set of artifacts – a series of modern cotton gins. This new evolutionary series began almost immediately after Whitney's model was put to work. The widespread use of the Whitney-inspired gins owed as much to his inventive genius as it did to environmental, social, economic, and political conditions that favored the cultivation of cotton in America and elsewhere.

Several lessons can be drawn from the Whitney story. The obvious one is that Whitney's invention of the cotton gin was part of the evolutionary development of technology. Less obvious is the realization that all variants of an artifact are not of equal importance. Some are simply inoperable; some are ineffective; and some are effective but have little technological and social influence. Only a few variants have the potential to start a new branching series that will greatly enrich the stream of made things, have an impact on human life, and become known as "great inventions" or "turning points in the history of technology."

Recognition of the significance of Whitney's cotton gin depended on the growing demand at home and abroad for cheap cotton and the limited availability of slave and paid laborers to process the raw material manually. In a society dominated by woolen or linen cloth, or in one in which cheap manual labor was freely available, Whitney's machine would not have served as the prototype for a spate of more powerful and effective gins. In either of those alternative societies, the cotton gin would have been a mechanical curiosity without social, economic, or technological influence.

Thus, the significance of an invention cannot be determined solely by its technological parameters – it cannot be evaluated as if it were a thing unto itself. An invention is classified as "great" only if a culture chooses to place a high value upon it. Likewise, the reputation of its inventor is tied to cultural values. In either of the alternative worlds just described, Whitney would not be honored as a heroic inventor; he would be ignored or at best be looked upon as the eccentric builder of a trivial device.

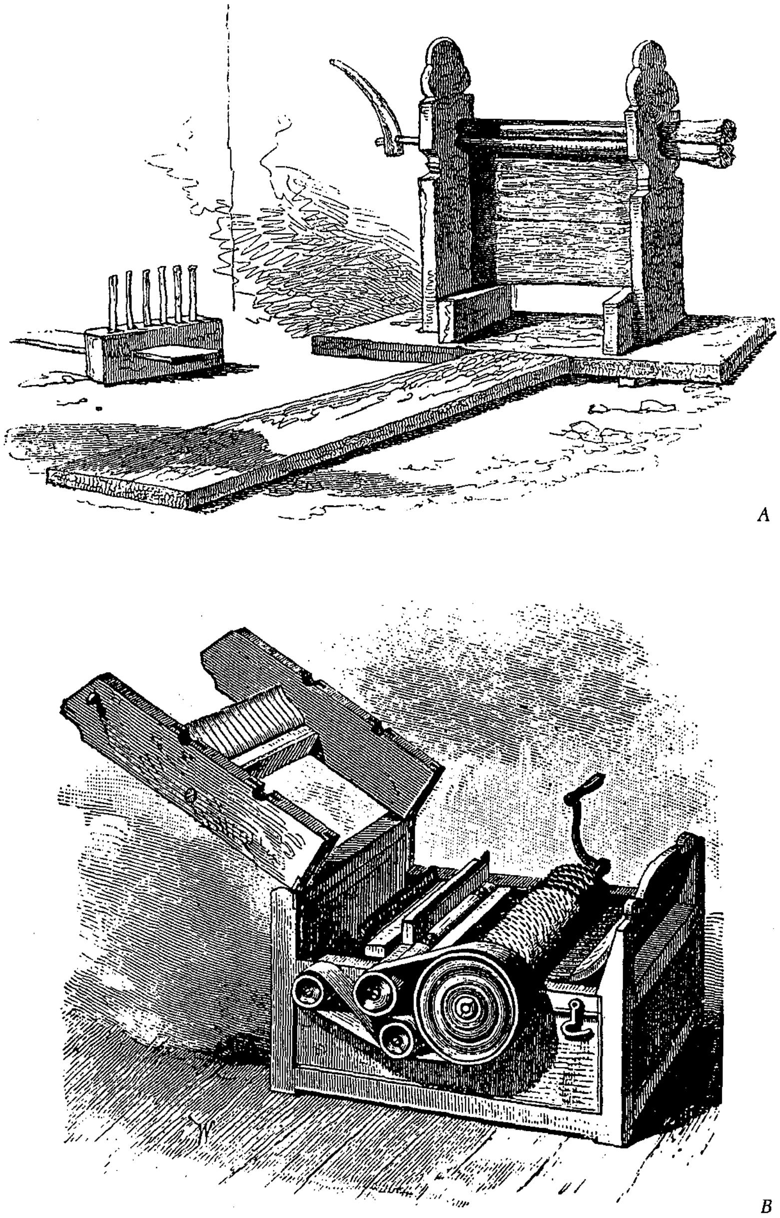
Steam and Internal Combustion Engines

The cotton gin was the most important technological contribution to the growth of the American South's economy between 1790 and 1860. At about the same time, the steam engine played a somewhat comparable role in the British economy. Like the cotton gin, it, too, has been popularly viewed as a contrivance with virtually no history. In 1842 W. Cooke-Taylor, a commentator on the British industrial scene remarked: "The steam engine had no precedent . . . [it] sprang into sudden existence, like Minerva from the brain of Jupiter."[2] Or did it spring from the brain of James Watt?

Popular accounts tell us that young James Watt was inspired to invent the steam engine as he watched steam rising from the spout of a tea kettle (Figure II.3). The fanciful legend is undermined by the fact that working Newcomen steam engines existed in England at the very moment Watt was contemplating vapors from the boiling tea water. Some sixty years separate the appearance of Thomas Newcomen's working atmospheric steam engine in 1712 and the completion of a successful full-sized steam engine by Watt (1775). To complicate the matter further, Watt's version of the steam engine grew out of his dissatisfaction with a small-scale model of a Newcomen engine he was asked to repair.

The Newcomen engine utilizes the condensation of steam to create a partial vacuum beneath a piston, which is then forced down by the greater atmospheric pressure acting on its outer surface. Because the engine was devised to pump water from mines, it took the form of a long pivoting beam with pump rod attached to one end and a piston rod to the other. A large piston (five to six feet in diameter) was fitted into a cylinder that had inlets for steam and the cold water used to condense the steam, and with an outlet for the waste water. After the pressure of the atmosphere had pushed the piston down to its lowest position, and lifted the pump rod to its maximum height, the weight of the pump mechanism caused the pump end of the beam to descend, raising the piston and making it possible to fill the cylinder with steam again so that the cycle could be repeated (Figure II.4). Two aspects of this engine deserve special attention: first, the weight of the atmosphere, not the expansive power of steam, did the work; and second, the cylinder was alternately heated and cooled as steam and cold water were injected into it.

In the winter of 1763/4, when Watt began his repair and study of a model Newcomen engine, the larger versions were an established power source in half the world. Despite its widespread use, some



of the features of the Newcomen engine troubled Watt and in attempting to remedy them he produced a machine that supplanted Newcomen's and prepared the way for the modern steam engine.

Watt realized that the efficiency of Newcomen's engine could be increased if the cylinder were kept uniformly hot instead of heating and cooling it during each cycle. This he accomplished by insulating the cylinder and then condensing the steam in an adjoining container that was kept constantly cool for just that purpose. In addition he abandoned the use of atmospheric pressure and moved the piston first in one direction and then in the opposite direction, by applying steam first to one side and then to the other side of the piston. Expanding steam pushing against the piston did work in a Watt engine. Thus was born the double-acting steam engine with a separate condenser. It first appeared in 1784 and dominated steam engine design for the next fifty years.

In exchanging Newcomen for Watt as the inventor of the steam engine, the issue of continuity has not been resolved; the temporal focus of the investigation has merely been changed. The question now becomes: Did the Newcomen engine appear on the scene without any antecedents? Again, the answer is no. Some of the mechanical elements that made up the Newcomen engine can be traced back to early seventeenth-century Europe, others had their origin in thirteenth-century China, and still others first appeared a century or two before the birth of Christ.

Because a Newcomen engine is mechanically more complex than a cotton gin, its antecedents are more difficult to trace in a succinct fashion. Evacuated chambers, piston pumps, steam displacement

Figure II.2. A. An Indian *charka*, or roller gin. The gin consists of two teak wood rollers that are rotated by turning the handle on the upper left side of the machine. When uncleaned cotton is fed between the moving rollers, the fibers pass through to the other side of the gin while the seeds remain behind and fall to the enclosure at the base. B. Eli Whitney's cotton gin opened for inspection. In operation the hinged top of the gin is closed, aligning the slotted breastwork of the top portion with the protruding wire teeth fixed to the large rotating cylinder. Rotation of the cylinder brings the uncleaned cotton to the breastwork slots, which are too narrow to permit passage of the seeds. Thus the seeds are torn away from the fiber and the fiber accumulates on the toothed cylinder. Another rotating cylinder, not shown here, is covered with bristles that brush the cleaned fiber from the large cylinder. Both the *charka* and Whitney's gin rely upon two rotating cylinders activated by a hand crank. Sources: A. Edward Baines, *History of the cotton manufacture in Great Britain* (London, 1835), p. 66. B. Mitchell Wilson, *American science and invention* (New York, 1954; copyright renewed © 1982 by Stella Adler, Victoria Wilson, and Erica Spellman), p. 80.

Figure II.3. Allegory on the significance of steam power, ca. 1850. The steam escaping from the boiling tea kettle inspires James Watt to invent the steam engine as well as envision its role in the creation of industrial civilization. This drawing is an excellent representation of the popular view that great inventions are the result of inspired intuitive leaps made by heroic figures. Source: Wolfgang Schivelbusch, *The railway journey* (Oxford, 1980), p. 5; Picture Collection, The Branch Libraries, The New York Public Library.

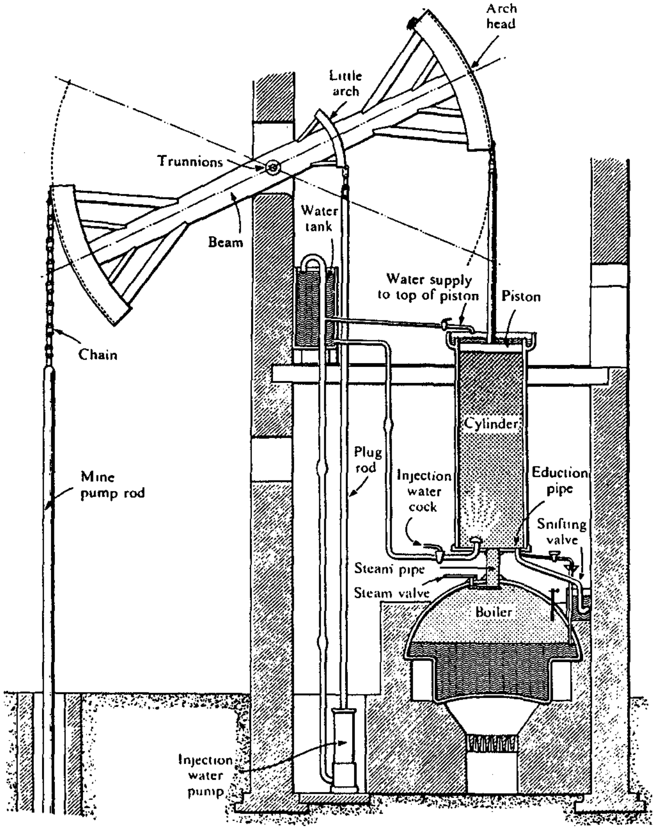


Figure II.4. Diagram of a typical Newcomen steam engine, ca. 1715. The steam-filled cylinder is about to be cooled by the injection of a spray of cold water into its interior. As a result of this action, the steam in the cylinder condenses, creating a partial vacuum. The weight of the atmosphere pressing on the piston's outer surface then forces the piston down for the engine's power stroke. When the piston reaches the lowest point on its path of travel, steam is injected into the cylinder equalizing the pressure on either side of the piston. The weight of the mine pump's mechanism then causes the beam to rotate lifting the piston to the top of the cylinder. Note that the valves and cocks that control the entry of the steam and cold water into the cylinder and the exit of the waste water through the eduction pipe are all hand-operated on this machine. Source: D. B. Barton, *The Cornish beam engine* (Bath, 1969), p. 17.

devices, and mechanical linkages all have their place in the prehistory of the steam engine. They form the "long chain of direct genetic connections" that historian Joseph Needham mapped in an essay entitled: "The Pre-Natal History of the Steam Engine." After assessing the contributions made by ancient Chinese artisans, Hellenistic mechanicians, and European natural philosophers, instrument makers, and mechanics, Needham concluded: "No single man was 'the father of the steam engine'; no single civilization either."[3] When scholars Maurice Daumas and Paul Gille investigated the background of the steam engine, they concluded that the atmospheric engine would probably have been invented in the first half of the eighteenth century even if Newcomen had never lived.

Like Whitney's cotton gin, Watt's steam engine was a seminal invention that spawned a manifold and divergent series of machines. The hot air and internal combustion engine are two of the most important power sources that have evolved from the steam engine. As early as 1759 hot air was proposed as a substitute for steam in an engine, but the first working model of such a device was not built until 1807. Later in the nineteenth century Robert Stirling, in England, and John Ericsson, in America, designed hot air engines that were sold to the public. By 1900 the hot air engine was supplanted by yet another variant of the steam engine, one that replaced the external combustion of the steam or hot air engine with an internal combustion within the cylinder. In 1791 an internal combustion pumping engine that ran on vaporized turpentine had been patented in England; however, the world's first production model of an internal combustion engine was designed by Belgian inventor Jean Joseph Etienne Lenoir in 1860. The Lenoir engine, fueled by illuminating gas, was closely patterned after a double-acting horizontal steam engine. Just as Watt's double-acting engine admitted steam on both sides of the piston and hence did work in both directions, Lenoir's engine exploded a gas and air mixture at both ends of the cylinder driving the piston forward and backward. Later improvements of the gas engine included Nikolaus Otto's single-acting four-stroke model of 1876, which served as the prototype of the modern automobile engine. Although the gaseous medium had been changed from steam to hot air to exploding mixtures of fuel and air, the basic configuration of cylinder and piston remained a constant.

The Electric Motor

Neither the cotton gin nor the engines we have considered were the immediate result of a major breakthrough in science. Therefore, one might ask, does technological change occur in a different fashion when it draws upon a recent scientific discovery? Perhaps a revolutionary development in science evokes a similar discontinuity in technology whenever it is applied in practice? To test this possibility, consider the discovery of electromagnetism by Hans Christian Oersted and its application in the earliest electric motors.

Oersted's announcement in 1820 that a current-carrying conductor produces a magnetic effect in its immediate vicinity created widespread interest throughout the scientific community. Startling as Oersted's discovery was to the world of science, its technological application followed a predictable course. The first electric motors were modeled after two well-known devices: the magnetic compass and the steam engine.

The Danish scientist had shown that a piece of wire carrying an electric current exerted a force on a compass needle causing it to deflect. An English physicist, Michael Faraday, having learned of this, immediately attempted to change the needle's deflection into continuous rotation. The result was the first electric motor. Granted, he achieved continuous rotary motion in a simple laboratory apparatus and not in a device capable of doing useful work; nevertheless, the principle of the modern electric motor had been elicited and demonstrated by Faraday. The needle of Faraday's modified compass spun continuously instead of aligning itself with the earth's magnetic field.

In 1831, within a decade of Faraday's experiments, American physicist Joseph Henry built an electric motor that drew upon steam engine mechanisms. A central feature of the Newcomen and Watt engines was a long, pivoting beam with piston connected to one end and pump rod or flywheel to the other, and Henry's new oscillating-beam electric motor likewise had a pivoting, elongated electromagnet that seesawed up and down making and breaking electric contact.

There was no electrical analogue for a cylinder and piston in Henry's motor, but several other inventors incorporated the cylinder and piston mechanism into their reciprocating electric motors (Figure II.5). Charles G. Page (1838), improving on Henry's design, used the beam as a mechanical element and converted the electromagnets into "cylinders" by shaping them as hollow coils of wire into which iron core "pistons" plunged when the "cylinders" were energized. A European inventor devised a motor with electromagnetic "cylinders and piston," beam crank, flywheel, connecting rod, eccentric valve gear, and slide rod and valves. With all of these traditional steam engine mechanisms included in the motor, only