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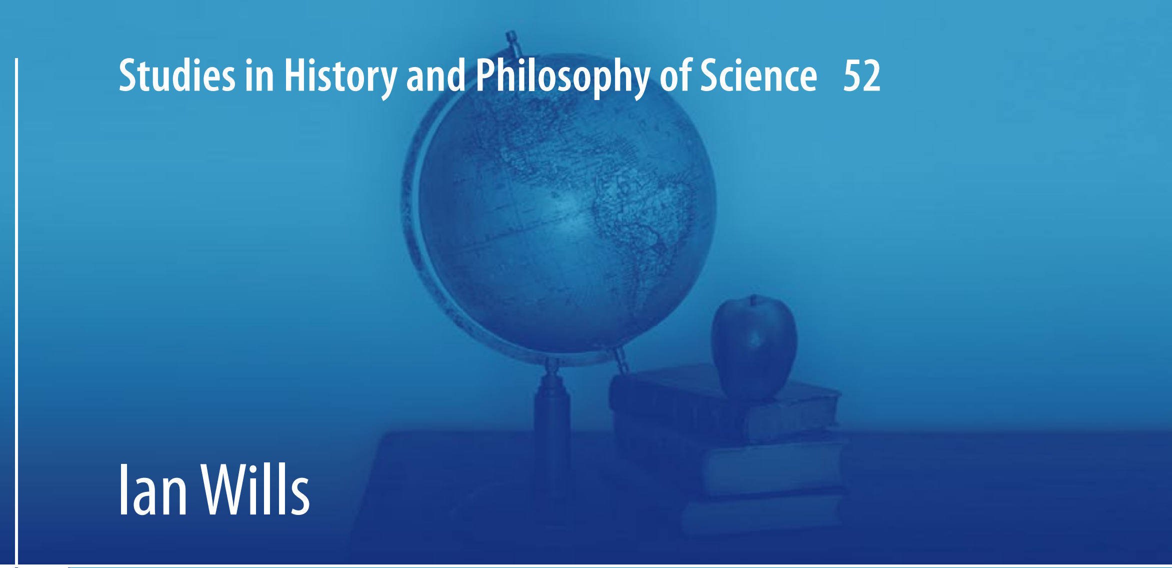

Ian Wills

Thomas Edison: Success and Innovation through Failure

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Chapter 1
Introduction

> Before I am done with it, I mean to succeed. I have the right principle and am on the right track, but time, hard work and some good luck are necessary too — It has been just so in all my inventions. The first step is an intuition, and comes with a burst — Then difficulties arise. This thing gives out then that. "Bugs" as such little faults and difficulties are called, show themselves — Months of intense watching, study and labour are required before commercial success — or failure — is certainly reached.[1]

Thomas Edison wrote this in a letter to an acquaintance in 1878, soon after starting work on his electric lighting system. It is a telling description of his way of inventing because his laboratory notebooks are filled with descriptions of bugs – things that "gave out" – and the ways in which he overcame them. Edison used the word bug for these problems so early and so frequently that he probably coined it. As early as 1873 he described a "bug trap" that overcame a bug in one of his telegraph inventions, 16 years before the earliest citation in the Oxford English Dictionary (1889), also from Edison.[2,3]

Bugs were a constant problem for Edison and his co-workers. One of them, Edison's 16 year old nephew Charles, drew Fig. 1.1 apparently out of frustration with bugs.[4]

This is not just an etymological anecdote because bugs, those "little faults and difficulties", were Edison's constant companions. Each bug, even if a "little fault", meant the failure of an invention to work as intended. Each bug, if ignored, could have rendered an invention a failure.

Failures they may have been, but they were not disastrous. Dealing with them and, at times, exploiting them, were crucial to Edison's way of working. Over his

[1]TAEB 4:1570.

[2]TAEB 2:348.

[3]Third edition Oxford English Dictionary, "Bug, N.2," (Oxford University Press, 2006). http://www.oed.com/

[4]Charles ('Charlie') Pitt Edison (1860–1879) Thomas Edison's nephew and promising inventor. After the death of James Adams, Charles Edison followed him to Paris where he too died, aged 19.

I. Wills, *Thomas Edison: Success and Innovation through Failure*, Studies in History and Philosophy of Science 52, https://doi.org/10.1007/978-3-030-29940-8_1

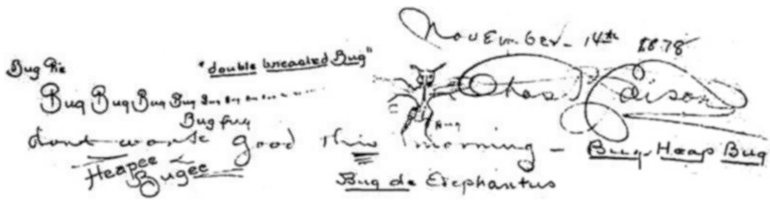

Fig. 1.1 Charles Edison's image of a bug (TAED NV18:84)

lifetime, Edison's attitude to bugs and failure generally was overwhelmingly positive. He could even be described revelling in them. A bug was not the ruinous end to a venture but a puzzle to be solved and perhaps an opportunity for new directions.

Despite many notable successes, Edison's career was also marked by many failures. The majority were minor failures, bugs, and known only to Edison and the people around him. After the failure of a crucial experiment, Edison commented that at least he had learnt that "the thing couldn't be done that way".[5] Edison certainly had learned that, but failures did more than just point to things that did not work. Indeed, he used failure so extensively and in so many innovative ways that his approach to it was fundamental to his prodigious inventive output. Failure was so significant to Edison's way of working that it is possible to follow his successes by following his failures. Chapter 2 relates how an embarrassing failure when demonstrating his automatic telegraph in 1873 led him to invent a variable resistor using carbon granules. The resistor in turn also failed to work as Edison intended but the cause of its failure, the sensitivity of carbon granules to vibration, became the basis for Edison's invention of the carbon microphone, a component crucial to the initial success of the telephone and used in most telephones for the next century.

Edison's fame comes from his public successes but a few of his failures were significant and very public, such as his claim to have discovered a new force of nature (Chap. 8) and the failure of the Naval Consulting Board, which he led during World War I, to produce any significant inventions for the war effort. Perhaps Edison's greatest failure was financial. This was his unsuccessful attempt to enrich iron ore using electromagnets. Edison lost the equivalent of 300 million dollars in today's monetary value in the venture but, turning failure into success, he adapted some of his ore processing inventions it the mass production of Portland cement, the basis of concrete. In so doing, he not only transformed financial failure into a commercial opportunity but also revolutionised construction in the twentieth century.

Thomas Alva Edison may have been born in obscurity in Ohio in 1847 but by the age of 31 was he was being described on both sides of the Atlantic as a genius and a

[5]Thomas A Edison, *The Diary and Sundry Observations of Thomas Alva Edison*, ed. Dagobert D Runes (New York: Philosophical Library Inc., 1948), 43.

magician.[6,7] By the time of his death in 1931 he had become a national treasure symbolising American ingenuity and inventiveness. Edison applied for his first patent in 1868 at the age of 21 and his last in 1931 aged 84. He remains America's most prolific inventor with almost 1100 patents to his name.

Edison received only a few months of formal education (he was largely home schooled by his mother) and began work at 12 selling newspapers on the local railroad. In his teens, he worked as an itinerant telegrapher, inventing in his spare time but by 22 was a full time inventor. His inventive output was prodigious, peaking at over 100 patents in 1 year. Initially ridiculed for making extravagant claims, Edison came to be known for producing near-miraculous inventions like the Phonograph, electric lighting and motion pictures. He was the Wizard of Menlo Park.

Early in his career Edison learnt that to protect his inventions from competitors, he needed detailed records of his progress in developing them. These records served as evidence in possible (often inevitable) future patent litigation. This practical need resulted in the accumulation of a huge amount of documentation. Edison's celebrity meant that that the documents were preserved after his death and are currently being published progressively by the *Edison Papers* project at Rutgers University.[8]

My interest in Thomas Edison began with a chance encounter with the book edition of the *Edison Papers*.[9] Leafing through the pages I was surprised to find that I could recognise the thought processes recorded in his laboratory notebooks. They were processes I was familiar with as an engineer developing new designs. Here were the kind of successes, failures, musings, discussion of options, blind alleys followed, mistaken assumptions, and so on, that are part of the process of creating something new.

Apart from being the papers of an exceptional person, the papers themselves are exceptional because they preserve these processes. The norm, in my experience, is that while similar records of conventional projects may be held in for a few years or even archived, almost all are discarded over time. Moreover, while practitioners in most areas including engineering and scientific research may be successful at what they do, they tend to be poor at describing how they did it. The result is that their retrospective explanations are often inaccurate and incomplete, particularly in relation to problems (bugs) overcome and even the recollection of why past difficulties were even difficulties.

In contrast, the *Edison Papers* preserve an easily accessible gold mine of material that can be used to study Edison's approach to inventing and by extension, the

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[6]Washington Post. "Genius before Science." *Washington Post*, 19 April 1878.

[7]TAED MBSB1:171.

[8]Thomas A. Edison Papers. 2019. "Thomas A. Edison Papers." [web site]. The Thomas Edison Papers, Rutgers, The State University of New Jersey. http://edison.rutgers.edu/

[9]Thomas A Edison, *Menlo Park: The Early Years, April 1876–December 1877*, ed. Paul B Israel, Keith A Nier, and Louis Carlat, vol. 3, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 1989).

process of innovation more generally. The papers show Edison inventing as he did it, rather than what he remembered decades later. This book contains processed ore from the *Edison Papers* gold mine. While previous accounts of Edison's approach to inventing, including his own, acknowledge his relentlessly positive attitude to failure, they have not addressed the significance of failure both to his success as an inventor and its role in the breadth and number of his inventions. Examining Edison's failures also highlights the importance of failure to innovation more generally; for those who seek to produce something that is both new and successful must be serious in their approach to failure.

This book is divided into four parts examining Edison at work and extending the conclusions drawn from Edison at work to issues of innovation more generally.

1.1 Part I: Edison and Failure

Part I focuses on Edison's use of failure to create inventions. It begins with a detailed examination of Edison's path to one of his most important but lesser known early inventions, the carbon microphone. This invention was important because it transformed Alexander Graham Bell's rudimentary telephone into a practical system, capable of transmitting sound over hundreds of kilometres rather than just between rooms.[10] Edison's development of the carbon microphone illustrates the many ways he used failure in addition to eliminating alternatives. Crucial to this process is the identification of success criteria, that is, the criteria used to judge whether or not something succeeds or fails.

Examples taken from Edison's development of the carbon microphone are used to develop a theoretical approach to failure and success that is applicable to not only to Edison's successful inventions, but to success and failure generally.

Part I then turns to the question of systems, developing the concept of the functional system as a way of understanding inventions and innovation generally. (A functional system is a collection of components that interact and are related by a

[10]Alexander Graham Bell (1847–1922) Bell was a Scottish-born inventor-entrepreneur who initially followed his father in becoming a teacher of the deaf. Bell migrated to Canada, later moving to the United States, there taking as a student Mabel Hubbard, the deaf daughter of Gardiner Hubbard a prominent Boston lawyer and financier. Bell had been experimenting with automata that produced speech and with telegraphy for some years and at Gardiner Hubbard's suggestion developed his own ideas for the telephone. In 1877 Bell married Mabel Hubbard and in the same year, with her father's assistance, established the Bell Telephone company. Bell's telephone patent was recognised over competing claims including that of Elisha Gray giving the company a monopoly on the telephone. Bell's priority and honesty in relation to the invention of the telephone have been questioned. Conot claims that a patent examiner was bribed to show Gray's patent caveat to Bell. Bell was later charged with larceny in connection with Antonio Meucci's telephone but the case did not come to trial due to Meucci's death. Bell subsequently withdrew from active involvement in the company that bore his name, turning to non-commercial interests that included founding and becoming president of the National Geographic Society.

structure in order to perform functions. Large technological systems like electric lighting utilities are discussed in Part III.) Using functional systems as an analytical tool, it shows that even simple inventions like Edison's first Phonograph can have a very large numbers of possible solutions, few of which will be successful. This is significant because it refutes a criticism of Edison that he was merely a lucky tinkerer because this low probability of accidental success rules out luck as significant in Edison's huge inventive output.

These concepts are then used to address questions of innovation and novelty. Its most significant conclusion is that a successful innovation is the sum of its failures: the more successful it is, the more it has failed. The consequence of this is that not only should we expect innovations to fail, we should want them to fail. We should also be sceptical of innovations that appear to have been created with few failures since it means either that are likely to fail in the future or that their creation involved little innovation.

To this point, failure has been used in a broad sense. Part I concludes with an examination of a specific type of failure, catastrophic failure, that is a failure in which the artefact is either destroyed or severely damaged, often at considerable economic and human cost. It discusses some examples of catastrophic failures that resulted from altering success criteria so that what previously would have been classed as failures came to be treated as successes but ultimately failed catastrophically. It also concludes that innovation in complex systems is inherently likely to lead to catastrophic failure.

1.2 Part II Edison, Science and Invention

If Edison had a positive attitude to failure, he was even more positive about success. Part II looks at Edison's positive reaction to two notable observations. One of these observations produced a revolutionary invention. The other led to a failure that was so significant it almost ended Edison's plans for his Menlo Park laboratory. The revolutionary invention is the Phonograph. This is approached through a combination of historic analysis of Edison's papers and an experimental replication of his first Phonograph experiments. After his first successful sound recording, Edison wrote in his laboratory notebook that there was "no doubt" he would be able to record and reproduce the human voice "perfectly". Replication of that experiment suggests that this was a remarkably bold claim because what he heard that night would have been unrecognisable as a human voice. Tracing Edison's progress from this first crude experiment to a successful Phonograph instrument 5 months later provides insights into why it was Edison and not someone else who produced the first successful recorded sound.

While the Phonograph was an international success, Edison's public and widely disputed claim to have discovered a new force of nature was not. Like the Phonograph, it began as a remarkable leap from meagre evidence. Seven months before Edison's first sound recording experiment he concluded, based on one observation of an anomalous phenomenon, that he had discovered a new force of nature he called Etheric force. The claim became an early and very public failure for Edison. Yet his failure was not because he was an inventor who did science badly but because, when he moved from inventing to developing a scientific theory, he abandoned the approaches he successfully used as an inventor. Subsequent research revealed that Edison had, indeed, observed something revolutionary, not a new force of nature, but wireless transmissions. Had Edison approached Etheric force differently, he may well have become a pioneer of wireless.

1.3 Part III Edison's World

Part III turns to aspects of the world in which Edison worked. It begins with the American patent system, the system that enabled Edison and other professional inventors to thrive. It also shaped what Edison did. Analysis of patterns evident in Edison's 1086 American utility patents reveals, for example, that he did not invent to with the primary aim of creating large technological systems like electric lighting, but was an opportunist for whom large technological systems presented many opportunities for inventions and patents.

The world of the inventor is, of necessity, one of limited knowledge. Part III examines trial and error, Edison's preferred way of dealing with limited knowledge. When he began developing the carbon microphone there was no existing theory applicable to the vibration sensitivity of carbon. Edison's solution to this lack of theory was to use trial and error, an approach that became so identified with him that it is sometimes called the Edisonian Method. Derided by many (Nicola Tesla called it "inefficient in the extreme"), closer examination reveals that, far from being inefficient and the last resort of the ignorant and uneducated, trial and error is an efficient approach that can be used when no relevant theory exists, including by scientists working at the edge of current theory.

1.4 Part IV Reversing Edison

Previous chapters look at how Edison progressed from the functions he wanted his inventions to perform, to the form the inventions needed to achieve those functions. Part IV asks whether it is possible to reverse this process, that is, use the form of something to determine its function. Specifically, it examines the claim made by philosopher of biology Dan Dennett, that biology is the reverse engineering of natural systems. Drawing on examples from previous chapters and from the techniques of reverse engineering used by engineers, it concludes that we should not be confident that we can identify the functions of something, be it made by humans or nature, from an examination of its form.

1.5 Citing the Thomas A. Edison Papers

Thomas Edison's papers total over three and a half million pages. Selections are published in several forms by the Thomas A. Edison Papers project including an edited and annotated book series, a digital (on line) edition and a microfilm edition. In this book only the first two are cited.

1.6 The Thomas A. Edison Book Edition (TAEB)

Citations designated TAEB refer to documents in the Thomas A. Edison Papers book edition. Currently, the seven published volumes cover the period from Edison's birth in February 1847 to December 1884.[11] Documents in the book edition are numbered consecutively across the volumes and it is the document number, rather than page number, that is cited using TAEB notation. In the citation "TAEB 2:679n5", TAEB indicates the Thomas A. Edison Papers book edition, 2 the volume number, 679 the document number and n5 note 5 to document 679.

1.7 The Thomas A. Edison Papers Digital Edition (TAED)

TAED citations refer to documents in the Thomas A. Edison papers digital edition and use the citation method suggested by the Thomas A. Edison papers editors.[12] For example, in the citation TAED SB1677:126, TAED indicates the Thomas A. Edison

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[11]Thomas A Edison, *The Making of an Inventor, February 1847–June 1873*, ed. Reese V Jenkins, et al., vol. 1, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 1989).

From Workshop to Laboratory, June 1873–March 1876, ed. Robert A Rosenberg, et al., vol. 2, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 1989).

TAEB 3, 3.

The Wizard of Menlo Park, 1878, ed. Paul B Israel, Keith A Nier, and Louis Carlat, vol. 4, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 1998).

Research to Development at Menlo Park, January 1879–March 1881, ed. Paul B Israel, et al., vol. 5, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 2004).

Electrifying New York and Abroad, April 1881–March 1883, ed. Paul B Israel, et al., vol. 6, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 2007).

Losses and Loyalties, April 1883–December 1884, ed. Paul B Israel, et al., vol. 7, The Papers of Thomas a Edison (Baltimore: Johns Hopkins University Press, 2011).

[12]Thomas A. Edison Papers. 2019. "Citing Edison Papers Documents." [web page]. The Thomas Edison Papers, Rutgers, The State University of New Jersey. http://edison.rutgers.edu/citationinst.htm

Papers digital edition, SB1677 is the Folder/Volume ID in the Thomas A. Edison papers digital edition database and 126 the image number in that Folder/Volume. Document images can be accessed through the Thomas A. Edison Papers website using the Folder/Volume ID to locate the folder, then the image number within the folder.[13]

[13] 2019. "Search Method: Retrieve a Single Document or Folder/Volume." [web page]. The Thomas Edison Papers, Rutgers, The State University of New Jersey. http://edison.rutgers.edu/singldoc.htm

Part I
Edison and Failure

Chapter 2
Success, Failure and Innovation: The Carbon Microphone

2.1 Edison's Dilemma

Thomas Edison was remarkably positive in the face of failure. Towards the end of his life, he related the following incident:

> I never allow myself to become discouraged under any circumstances. I recall that after we had conducted thousands of experiments on a certain project without solving the problem, one of my associates, after we had conducted the crowning experiment and it had proved a failure, expressed discouragement and disgust over our having failed "to find out anything". I cheerily assured him that we had learned something. For we had learned for a certainty that the thing couldn't be done that way, and that we would have to try some other way.[1]

Edison seems to have been fond of thinking of failure in this way because it appears in a number of other anecdotes. After the failure of many experiments on electrical storage batteries he was reported as saying that he did not regard the effort as wasted because "I know several thousand things that won't work" and another time that "I can never find the thing that does the work best until I know everything that don't do it!",[2,3] Clearly, since he was so fond of repeating it, Edison believed that this was how he used failure and did not mention the other many ways he used failure as a tool. It seems that Edison believed the value of failure was for finding "things that won't work".

Some of this chapter appeared previously in Ian Wills, "Instrumentalising Failure: Edison's Invention of the Carbon Microphone," *Annals of Science* 64, no. 3 (2007).

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[1]Edison, *The Diary and Sundry Observations of Thomas Alva Edison*, 43.

[2]quoted in Frank Lewis Dyer and Thomas Commerford Martin, Edison, His Life and Inventions, (Electronic Text Center, University of Virginia Library: (1998); New York: Harper and Brothers Publishers, 1910), http://etext.lib.virginia.edu/toc/modeng/public/Dye2Edi.html. Online text. 616.

[3]Martin André Rosanoff, "Edison in His Laboratory," *Harpers Magazine* 165, no. September (1932).

I. Wills, *Thomas Edison: Success and Innovation through Failure*, Studies in History and Philosophy of Science 52, https://doi.org/10.1007/978-3-030-29940-8_2

The implication that he succeeded by conducting a large number of experiments that failed until he eventually stumbled on one that worked cannot explain Edison's many successes. The fundamental problem with trying to succeed by building a long list of things that do not work is that this knowledge alone tells nothing of what might work. Edison clearly knew how to make things that worked and certainly revelled in success, so how did he use these many failures to arrive at eventual success? The first step in answering that is to recognise that Edison did not regard failure as a negative to avoid but as something actively pursued. It was a tool for moving towards success.

To see how Edison used failure as a tool, we will follow development of the carbon microphone, crucial to making the telephone a technical and commercial success and a technology that was central to the telephone for the next century. Anyone who has used a telephone with a rotary dial will almost certainly have spoken through a version of Edison's carbon microphone.

2.2 Edison and the Telephone

Although the name of Alexander Graham Bell is most often associated with the invention of the telephone, Edison played a significant part in making it viable through his invention of the carbon microphone. He was not the only claimant to a patent for this critical device and became involved in a 15-year legal battle with eight others, including Alexander Graham Bell, Elisha Gray (founder of the Western Electric Company) and Emile Berliner, inventor of the Gramophone.[4,5,6] These competing claims (patent interference) ended in 1892 when Edison was issued with two patents for the carbon microphone. By that time the Bell Telephone Company had purchased the rights to both Edison's and Berliner's designs.[7] Significantly, the litigation did not include Italian born American, Antonio Meucci, recognised by the United States Congress in 2002 as the inventor of the telephone.[8,9]

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[4]TAED TI1:2.

[5]Elisha Gray (1835–1901) American inventor entrepreneur. Gray was a prolific Chicago based inventor of electrical devices and partner in the firm that was later to become Western Electric.

[6]Emile Berliner (1851–1929) German American inventor. Berliner emigrated from Germany to America and, like Edison and Gray, was a professional inventor-entrepreneur. His best known invention is the gramophone, a device similar to Edison's phonograph. The gramophone employed flat disks that eventually displaced Edison's cylinders.

[7]Thomas A Edison. Speaking-Telegraph [1]. US Patent 474,230, filed 27 April, 1877, and issued 3 May, 1892; Speaking-Telegraph [2]. US Patent 474,231, filed 20 July, 1877, and issued 3 May, 1892.

[8]*Resolution 269*. Bell was charged with larceny in connection with the theft of Antonio Meucci's telephone model but did not go to trial due to Meucci's death.

[9]Antonio Meucci (1808–1889) Italian American inventor and manufacturer. Meucci demonstrated a telephone in New York in 1860.

2.3 Challenges to Western Union

Edison's invention of the carbon microphone was the consequence of the battle for control of the telegraph industry fought, in part, through patents. In the 1870s, the American telegraph industry was dominated by Western Union, which at one point transmitted 90% of all telegraph messages in the United States.[10,11] Alexander Graham Bell's telephone patent and Elisha Gray's harmonic telegraph patents represented a threat to this dominance.[12,13] Both technologies had the potential to dramatically reduce the cost of sending telegraph messages for the telegraph company that controlled them, Bell's by sending them as spoken messages rather than by Morse code and Gray's by sending many Morse code messages simultaneously down the same wire.

Western Union countered these threats in a number of ways, one of which was to commission Edison to invent devices to circumvent Bell's and Gray's patents. Edison's telegraphy inventions, notably the duplex and quadruplex telegraphs (which enabled two and four messages respectively to be sent simultaneously on the same wire), and his improvements to the printing telegraph (stock ticker) had significant commercial impact. This ability to produce successful inventions, seemingly on demand, brought Edison to the attention of the men behind the telegraph companies, notably Cornelius Vanderbilt, the largest stockholder in Western Union, and its president, William Orton.[14,15]

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[10]Robert E Conot, *A Streak of Luck*, 1st ed. (New York: Seaview Books, 1979), 37.

[11]The Western Union Telegraph Company was formed in 1856 following a number of mergers of smaller telegraph companies. At one time Western Union transmitted 90% of telegraph messages, entering the money transfer business in 1871 and, in 1878, telephone business using Edison's telephone inventions. When Bell Telephone challenged the legality of the latter venture, Western Union's sold its telephone interests to Bell. The telephone and later technologies led to a decline in Western Union's business to the point that currently only the money transfer business remains. Western Union delivered its last telegram on Friday 27 January 2006.

[12]Alexander Graham Bell. Improvement in Telegraphy. US Patent 174,465, filed 14 February 1876, and issued 7 March 1876.

[13]Elisha Gray. Improvement in Electric Telegraphs for Transmitting Musical Tones. US Patent 166,095, filed 19 January 1875, and issued 27 July 1875; Improvement in Transmitters for Electro-Harmonic Telegraphs. US Patent 165,728, filed 28 June 1875, and issued 20 July 1875; Improvement in Receivers for Electro-Harmonic Telegraph. US Patent 166,094, filed 28 June 1875, and issued 27 July 1875; Improvement in Local-Circuit Breakers for Electro-Harmonic Telegraphs. US Patent 194,671, filed 15 February 1875, and issued 28 August 1877.

[14]Cornelius Vanderbilt (1794–1877) American Civil War Commodore, shipping and railway magnate and one of the richest men in America. Patriarch of the Vanderbilt financial empire, Cornelius built his wealth first in shipping then railroads. Vanderbilt was also a major stockholder in Western Union, making him a competitor to Jay Gould in both railroads and telegraph.

[15]William Orton (1826–1878) American industrialist. Orton became President of Western Union in 1867 and continued in the position until his death. It was Orton who arranged for Western Union to finance Edison's plans to build his research laboratory at Menlo Park.

When Edison patented his quadruplex telegraph system, he initially offered it to his former employer, Western Union. Since the quadruplex enabled four messages to be sent simultaneously on one wire, it had the potential to increase the revenue producing capacity of Western Union's network fourfold with little additional capital cost. At the end of 1874, negotiations with Western Union had dragged on for months without resolution so Edison, under pressure from his creditors, licensed the quadruplex to Western Union's rival, Jay Gould's Atlantic and Pacific Telegraph Company.[16] Gould, who had ruthlessly built a railway empire, intended to repeat his success with the telegraph.[17]

During his negotiations with Western Union, Edison supplied Western Union with several prototypes of the quadruplex. Western Union's president, William Orton, dealt with Edison's defection to Gould by ignoring his patents and had the prototypes copied. This was something Gould could not ignore. In the court battle that followed, Edison appeared as a witness for Gould's Atlantic and Pacific Telegraph Company but, having resolved his differences with Western Union, Edison spent much of his time during the hearings in Western Union's offices.

The quadruplex case was a salutary lesson for Orton, who determined to keep Edison in the Western Union camp rather than risk his inventive talents being used by competitors. Edison also drew several lessons from the quadruplex case. One was to be wary of becoming "a tool of Wall Street" although he was obliged to draw on Wall Street capital to exploit his inventions until he became independently wealthy. In 1893, after losing control of his electrical companies, Edison determined to be his own entrepreneur in future. The other lesson was to record the development of his inventions in laboratory notebooks which could later be tendered as evidence in the inevitable event of his patents being contested. Those laboratory notebooks provide the basis for this study of Edison at work.

When Western Union could not overcome the Atlantic and Pacific Telegraph Company by other methods, it neutralised the threat by forming a price-setting cartel with Gould, later buying Gould's company. The move was typical of trusts in post-Civil War America, Western Union's telegraph system and Jay Gould's railways being just two. Edison came to understand the value of his inventions to reinforce or, in the hands of others, diminish Western Union's near monopoly of the telegraph. The potential of his quadruplex to significantly reduce costs could have made the Gould's Atlantic and Pacific Telegraph Company a serous rival to Western Union.

[16]Conot, *A Streak of Luck*, 66.

[17]Jay Gould (1836–1892) American financier. Gould seemed to set no limits on what he might do to achieve his financial ends. When he invested heavily in railroads Gould resorted sometimes to devious means to take over smaller railroads.

2.4 Edison Starts Work on the Telephone

Edison started work on circumventing Bell's telephone patent in mid-1875 with a number of disadvantages. Unlike Bell, who as a teacher of the deaf with a thorough understanding of the mechanisms of speech and hearing, Edison knew little of this and was partially deaf himself. Edison also began with only two exemplars, both of them of limited value. The first was Bell's telephone, which he could not use because of Bell's patent while the second, the German Philip Reis's *telephon*, transmitted only musical tones and not speech.[18,19]

Figure 2.1 shows the final form of Edison's carbon microphone, the design that Western Union put into commercial production in mid-1878. In the carbon microphone, sounds enter the horn shaped mouthpiece (M) causing the diaphragm (D) to vibrate. This vibration is transmitted via an aluminium button (A) to carbon particles (C) causing their electrical resistance to vary in sympathy with the sound. The screw S can be used to compress the carbon particles (Edison used lamp black, purified soot from oil lamps) which are confined in a small space but able to deform under pressure. When pressure caused by the entering sound is applied to the lamp black, this deformation changes the contact area between adjacent particles, and hence the electrical resistance. For a constant applied voltage, Ohm's law indicates that the electrical current passing through the carbon also varies in sympathy with the sound.

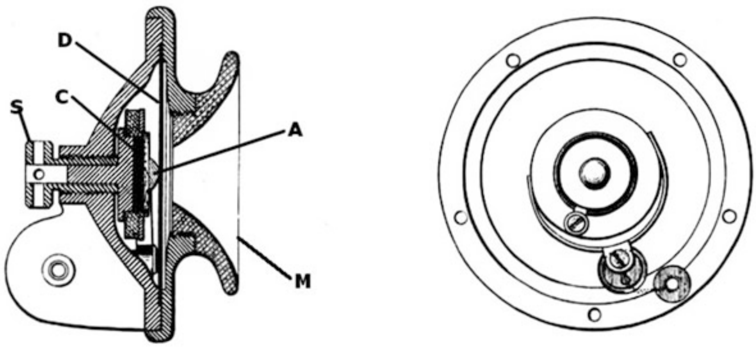

Fig. 2.1 Edison's telephone transmitter (notation added). (TAED TI2:490)

[18]V Legat 1862. "Reproducing Sounds on Extra Galvanic Way." http://edison.rutgers.edu/singldoc.htm as TI2:456–458.

[19]Philip Reis (1834–1874) German inventor, and teacher of mathematics and physics. Reis built and demonstrated a device for transmitting sounds by electricity. It was Reis who coined the name telephone, ("Telephon" in German). Reis's telephone apparatus was demonstrated in New York in 1872 and described in Baile's, *Wonders of Electricity* a book read by Edison and Bell. Edison based his first telephone sketches on Reis's instrument.

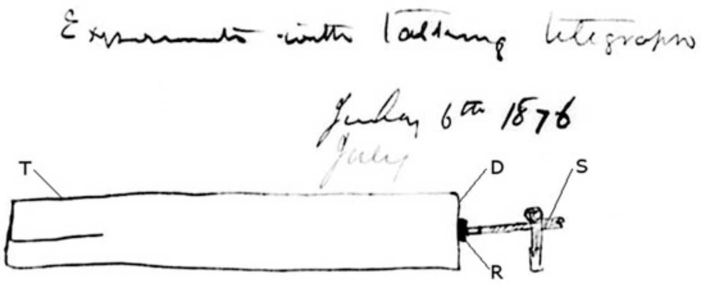

Fig. 2.2 Detail of Edison's sketch of 6 July 1876. The handwritten text reads "experiments with talking telegraph July 6th 1876". The electrolyte saturated felt variable resistance is the black rectangle (R). A screw (S) adjusts the pressure of the felt against the diaphragm (D) at the end of the speaking tube (T). (TAED TI2:34)

Figure 2.2 is one of Edison's earliest dated telephone sketches. It shows a speaking tube (T) at the end of which is a diaphragm (D). The variable resistance (R) (a piece of felt saturated with electrolyte) is pressed against the diaphragm by a screw (S). Apart from the material used as a resistance and the shape of the speaking tube, the device uses the same operating principle to the production version in Fig. 2.1. This similarity appears to support the popular belief that invention consists of an initial flash of inspiration in which the inventor conceives the successful solution followed by a period in which the remaining details are worked out. Following Edison through the development of the carbon microphone will show that this simplistic view is far from the inventor's experience because the path from initial concept to final solution was far from linear, with many false starts, dead ends and back tracking, and many, many failures.

2.5 Greenwich, England, 1873

Edison's carbon microphone had its origins in 1873, on the other side of the Atlantic, and with an embarrassing failure. In April 1873, 26-year-old Edison travelled to England to promote his automatic telegraph system, which was intended to increase the speed of telegraph transmissions by sending messages at a much higher speeds than they could be tapped out manually in Morse code or transcribed by the receiving operator. In use, operators at the sending end of the telegraph line recorded telegraph messages on perforated paper tape using conventional telegraph keys. This tape was then fed through a machine that transmitted the resulting code at high speed to the receiving end, where another machine, the recording telegraph, recorded the message as dots and dashes on chemically treated paper tape, the code being subsequently transcribed into text by telegraph operators.

Edison's trip began with some promise when he demonstrated the recording telegraph to the British Post Office, achieving speeds of 500 words per minute over short distances. This was slower than the 1000–1500 words per minute Edison claimed for his invention, but higher than achieved by the rival Wheatstone system, invented by the physicist Charles Wheatstone and used by the Post Office since the 1860s.[20,21]

To demonstrate the suitability of his recording telegraph for transatlantic transmissions, a further test was arranged using a cable at the Greenwich works of the Telegraph Construction and Maintenance Company. At the time, this company manufactured and laid most of the world's oceanic cables and had available 3500 km long cable awaiting laying between Europe and Brazil, the cable being stored in huge coils prior to loading onto a cable laying ship.[22] Despite never having worked with oceanic cables directly, Edison seems to have been confident of the suitability of his invention for this purpose.

The demonstration was anything but a success. As Edison told the story, the first dot he transmitted was printed not as a single dot on the recording tape but as "17 foot" (5 m) long dash. Despite working with his equipment for a fortnight, the highest speed Edison achieved was two words per minute, only a seventh of the guaranteed speed of the cable and far less than the 500 words per minute he had demonstrated earlier. Crucially, it was also less than the 10–17 words per minute achieved manually on transatlantic telegraph transmissions.[23]

2.6 Exploring Induction

The trip across the Atlantic made several negative impressions on the young Edison. The Atlantic crossing was so unpleasant that Edison named his shop, the *SS Java*, the "Jumping Java", the crossing souring Edison against overseas travel for life. (The only other overseas journey Edison made was a triumphal tour of Europe in 1889.)[24] Further, although the British Post Office reimbursed the cost of the demonstration, it did not buy Edison's invention, making the trip a commercial failure. Finally, the Greenwich demonstration was an embarrassing personal failure for a young man who prided himself on his knowledge of telegraphic technology.

In the circumstances, it would have been understandable had Edison to put the whole experience behind him and to move onto other projects. That was not Edison's

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[20]TAEB 2:591.

[21]Charles Wheatstone (1802–1875) English physicist and inventor. Wheatstone was prominent in the telegraph field and is best known for his invention of the Wheatstone bridge, a device for accurately measuring resistance. Apart from his inventions in telegraphy, Wheatstone also invented a musical instrument, the concertina.

[22]Edison, *TAEB 2*, 2, 5.

[23]Frank Lewis Dyer and Thomas Commerford Martin, Edison, His Life and Inventions, (Electronic Text Center, University of Virginia Library: (1998); New York: Harper and Brothers Publishers, 1910), http://etext.lib.virginia.edu/toc/modeng/public/Dye1Edi.html. Online text. 151.

[24]Conot, *A Streak of Luck*, 76.

way. Instead, as on many other occasions, he seized the Greenwich failure as a challenge. He may have been a puzzled man in Greenwich, but soon realised that the cause of his problem was electrical induction caused by the coiling of such a long cable. That he should have overlooked induction is itself puzzling for he claimed to have read and thoroughly digested Faraday's *Experimental Researches in Electricity* as early as 1868.[25] In Greenwich, Edison seems not to have connected the results of Faraday's experiments on small induction coils to the 3500 km coil of telegraph cable. Faraday had found that when a current passes through a wire it produces a magnetic field around the wire. Coiling the wire magnifies the magnetic field. Although the cable would have exhibited little inductance laid in a straight line under the ocean, when closely wound in its wells at Greenwich it became series of massive inductors. When Edison pressed his telegraph key, the coil stored the electrical energy as a large magnetic field then, when he released the key, the field collapsed, releasing electrical energy to produce the "17 foot dash".

Edison's realisation that his embarrassing failure at Greenwich was caused by induction piqued his interest to the point that he put aside inventing for much of the next year in order to explore induction phenomena, his patent output dropping to a seventh of what it had been the previous year. Edison continued his habit of experimenting night and day, as he had before he left for England, but focused on understanding induction rather than producing patentable inventions. His failure at Greenwich may have been a disappointment, but it highlighted oceanic cables as an inventive challenge, and Edison knew that inventive challenges were the catalyst of commercial inventions.

Once Edison had identified induction in the coiled cable as the cause of his Greenwich failure, he set about devising means of simulating the behaviour of long oceanic cables while avoiding induction effects. For this, he needed test devices that could simulate the capacitance, low inductance, and high resistance of the oceanic cables. Since these were not commercially available, Edison invented a high resistance rheostat (adjustable resistor) consisting of "heavy glass tubes filled tightly with flour of gas retort carbon", the tubes being "1/16 or 1/32 bore" (1.6 or 0.8 mm).[26] This was to be built in two versions that could simulate resistances of 1,000,000 ohms in steps of 50,000 ohms and 100,000 ohms in steps of 5000 ohms. Together these ingenious devices would have given Edison any resistance from 5000 ohms to 1,100,000 ohms in 5000 ohm steps, all in a very compact form.

Edison ordered ten of these but only one was finished (Fig. 2.3) because when tested, it failed to work as expected. Instead of the stable resistances he needed to simulate the cable, Edison "found that the resistance of carbon varied with every noise, jar or sound, and [the rheostats] were too unreliable where a definite resistance was required". He also noted, "The pressure of the electrodes in contact with the

[25]TAEB 1:7n3.

[26]TAEB 1:345

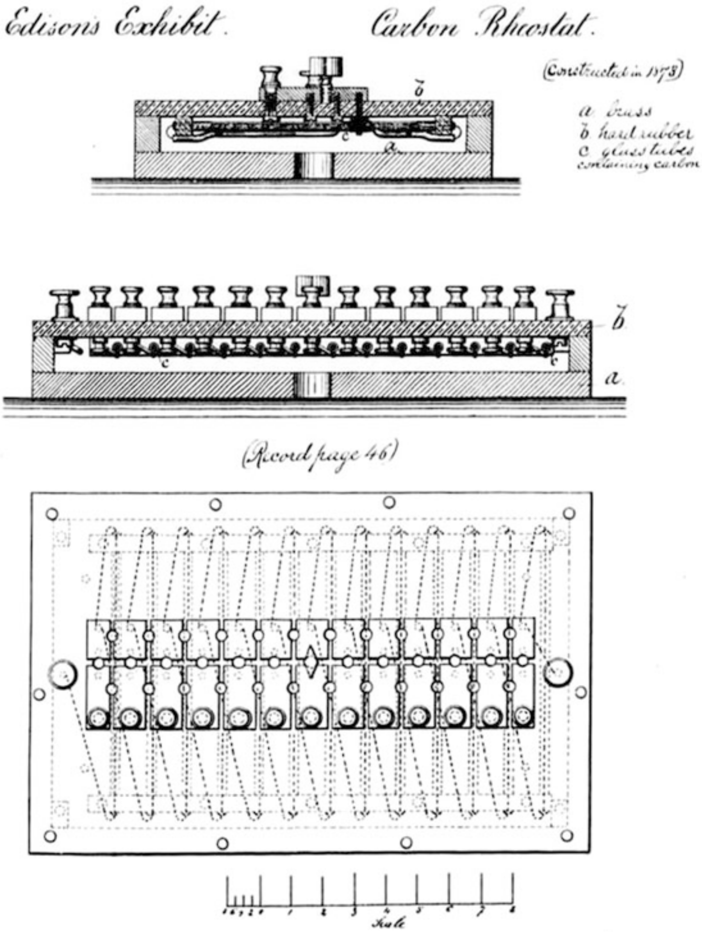

Fig. 2.3 Edison's 1873 carbon rheostat from his Telephone Interferences testimony. (TAED TI2:466)

carbon varied the resistance".[27] Edison abandoned the carbon rheostat for wire wound resistances but the recollection of the observed vibration sensitivity of carbon was to prove of value later.

One of the few instances of Edison's patent-directed work during this period dealt with diplex telegraphy.[28] The diplex enabled two telegraph messages to be sent in the same direction on the same wire and exploited reverse currents, an induction effect that occurs when the field in an electromagnet (in this case in a relay) collapses

27TAED TI1:41

28TAEB 2:348

following breaking of the circuit. Reverse currents in the relay sending one message caused unwanted movement in the relay sending the other message. They were, to use a term that Edison coined, a bug.[29]

To deal with the bug, Edison devised what he termed a "bug trap", in this instance another relay, adjusted to act slowly, so the reverse current did not interfere with the signal. Bug traps were a strategy that Edison used when he could not eliminate the cause of a problem, their objective instead being to render the effect of the bug insignificant.[30] The diplex telegraph system was to become the basis of the quadruplex telegraph, an even more ingenious and valuable invention that combined two diplexes, enabling four messages to be sent simultaneously on the same cable, two in each direction.[31]

2.7 Bell's Telephone

Bell's telephone was initially seen by Western Union, Edison, Gray and other telegraph experts as just another means for reducing the cost of sending telegraph messages.[32] While Edison's quadruplex and Gray's acoustic telegraph sent multiple messages using Morse code over the same telegraph wire, Bell's telephone would permit transmission at speaking speed. Instead of requiring skilled telegraphers, messages could be sent over telephone by cheaper untrained operators. Used in this way, a telephone operator would read the message over a telephone line to another operator at the receiving end, who would transcribe it to written text for delivery to the recipient. Except for transmission by speech, this was the process used for sending conventional telegrams. Neither Edison nor Orton imagined that the telephone would be used for direct person-to-person verbal communication.

Bell's invention was promoted by his father-in-law, Gardiner Hubbard, a prominent Boston lawyer and financier.[33] Hubbard approached Orton with an offer of the patent rights to the telephone, then in its early stages of development. Orton was

[29]Edison used the term bug so early and so frequently that he seems to have coined it. This patent, from August 1873, predates the earliest citation (1889, also from Edison) in the Oxford English Dictionary. Oxford English Dictionary, "Bug, N.2."

[30]Edison, *TAEB 2*, 2, 4.

[31]Ibid., 21.

[32]David A Hounshell, "Elisha Gray and the Telephone: On the Disadvantages of Being an Expert," *Technology and Culture* 16, no. 2 (1975).

[33]Gardiner Hubbard (1822–1897) Lawyer and financier. A member of a prominent Boston family, Hubbard engaged Alexander Graham Bell to teach his daughter, Mabel Gardiner Hubbard, who had become deaf as a result of contracting scarlet fever as a child. (Bell later married Mabel.) Through this contact, Hubbard encouraged Bell to develop telephone and with him established Bell Telephone company with Hubbard as its first president. Conot claims Hubbard was involved in dishonest activities in support of Bell including bribing patent office officials. Hubbard became a major stockholder in the Edison Speaking Phonograph Company.