Edison, Science and Artefacts

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Abstract

This paper contrasts the approach Thomas Edison used when dealing with his claim to have discovered a new force of nature, etheric force, to the approach he used to create successful inventions. It argues that he failed in this adventure into scientific theory making because an erroneous view of science led him to abandon techniques that made him America's most successful inventor. From this I develop an argument for viewing experimental science as an artefact creation process, like inventing, in which two of the artefacts created are theories and demonstration experiments that support the theories.

Keywords: Thomas Edison; etheric force; wireless; invention; theories; artefact creation; experiment.

1 Introduction

In November 1875, Thomas Edison made the startling claim that he had discovered etheric force, an "entirely unknown force [of nature], subject to laws different from those of heat, light, electricity or magnetism".[1] It was to be a brief and unsuccessful adventure into scientific theory making in which Edison not only failed to have his theory accepted but also failed to exploit a phenomenon that fell within an area in which he was an acknowledged expert, communication technologies, for etheric force was essentially wireless transmission. I will argue that he failed, in large part, not because he was an inventor who did science badly, but because he was an inventor who abandoned successful invention techniques when he engaged in scientific research. I propose that this can be understood by viewing science, like invention, as an artefact creation process and that creating successful scientific

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[1] Reese V Jenkins et al., eds., *The Papers of Thomas A. Edison, Book Edition*, 5 vols. (Baltimore: Johns Hopkins University Press, 1989-), Doc 678. Citations to the book edition of Edison's papers (designated "TAEB") refer to the document number rather than page numbers. Documents are located as follows:

- Documents 1 to 340: Reese V Jenkins, *The Making of an Inventor, February 1847-June 1873*, vol. 1, The Papers of Thomas A Edison (Baltimore: Johns Hopkins University Press, 1989).
- Documents 341 to 737. Robert A Rosenberg, ed., *From Workshop to Laboratory, June 1873-March 1876*, vol. 2, The Papers of Thomas A Edison (Baltimore: Johns Hopkins University Press, 1989).
- Documents 738 to 1163: Robert A Rosenberg, ed., *Menlo Park: The Early Years, April 1876-December 1877*, vol. 3, The Papers of Thomas A Edison (Baltimore: Johns Hopkins University Press, 1989).
- Documents 1164 to 1650: Paul B Israel, Keith A Nier, and Louis Carlat, eds., *The Wizard of Menlo Park, 1878*, vol. 4, The Papers of Thomas A Edison (Baltimore: Johns Hopkins University Press, 1989).
- Documents 1651 to 2073: Paul B Israel, ed., *Research to Development at Menlo Park, January 1879-March 1881*, vol. 5, The Papers of Thomas A Edison (Baltimore: Johns Hopkins University Press, 2004).

artefacts involves similar strategies to creating successful physical artefacts. The debate over etheric force was to be a contest of artefacts in which Edison, the iconic inventor, was beaten by the creators of a better artefact.

2 The etheric force debate

During the night of 22 November 1875, while experimenting with the device in Figure 1, Edison and his assistant, Charles Batchelor, noticed sparks at S, a point at which no current should have been flowing.[2] [3] On investigating further they found that they could also draw sparks from the end of a wire connected at X and that, when they connected the wire to a gas pipe, they could draw sparks throughout the room. To their amazement, they found they could even get sparks by bending the wire into a loop and touching it back onto itself.

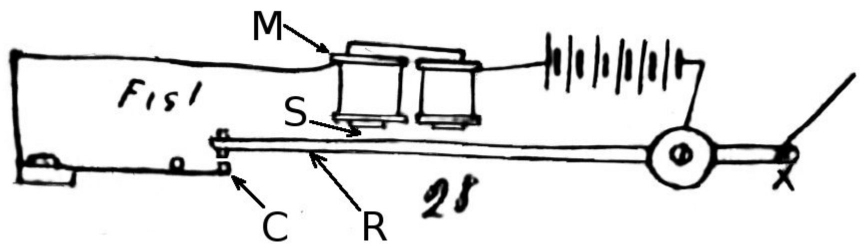

Figure 1 Device on which Edison first noticed etheric force sparks (notation added). When the contact C closes, the iron rod R is pulled towards the electromagnet M, opening the contact C and causing the rod to return to its original position. The process is cyclic causing the rod to vibrate.[4] In operating principle it is identical to an electric bell.

With this surprising but very limited evidence Edison wrote, "This is simply wonderful & a good proof that the cause of the spark is a true unknown force".[5] Edison continued to experiment with apparatus over the next few nights then announced his discovery to the press.

Newspaper reports began appearing on 29 November 1875, most being positive, using expressions such as "Wonderful Invention" and "Startling Discovery" to describe Edison's discovery and proclaiming that it would lead to a new era in communication.[6] [7] The *New York Herald* carried a lengthy that included Edison's etheric force theory. After describing how heat, electricity and magnetism could be converted into each other, Edison continued:

> It follows that if electric energy under certain conditions is transformed into that of magnetism under other conditions it might be transformed into an entirely unknown force, subject to laws different from those of heat, light, electricity or magnetism. There is every reason to suppose that etheric energy is this new form. The only manifestation of its presence previously recorded with scientific accuracy is that of the

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[2] Jenkins et al., eds., *TAEB*, Doc 665.

[3] Charles Batchelor (1845 - 1910). Batchelor was an English born textile mechanic who joined Edison in Newark in 1873 and was Edison's primary associate in invention for 20 years.

[4] Thomas A Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," http://edison.rutgers.edu/singldoc.htm, TAED NE1691:15. Citations to documents in the Edison Papers digital edition (designated TAED) use on the system recommended by the Edison Papers editors (see http://edison.rutgers.edu/citationinst.htm). For example, in this citation, 'TAED' indicates the Edison Papers Digital Edition, 'NE1691' is the volume or folder reference and '15' is image number in the folder. Individual documents can be accessed through http://edison.rutgers.edu/singldoc.htm using this notation.

[5] Jenkins et al., eds., *TAEB*, Doc 665. Double underlining in the original.

[6] Ibid., Doc 678 note 3.

[7] Ibid., Doc 678 note 5.

> German chemist Ruchenbach [sic] . . .This phenomenon, inexplicable to Ruchenbach, is easily to be accounted for on the etheric theory.[8]

The *Herald's* "Ruchenbach" was the German, Karl von Reichenbach. Reichenbach built a credible reputation (and a fortune) as a chemist in the 1820s and 30s, developing successful metallurgical techniques and identifying several organic compounds including creosote and pittacal, a synthetic dye. In the 1840s Reichenbach began experimenting with animal magnetism. His experiments led him to claim that he had discovered Od (or Odic force), a mysterious force in nature that he argued could explain phenomena as diverse as the Aurora Borealis and clairvoyance.[9]

Edison's mention of Reichenbach was injudicious. The *New York Times* seized on it publishing a highly critical report. The *Times* article parodied his gas pipe demonstrations and described the discoverer of Od as, "the maligned and discredited Reichenbach".[10] It emphasised the connection between Od (and by inference, etheric force) and "supernatural wonders" including clairvoyance. The article concluded with the ironic observation that Edison was wasting his time with gas pipes and should instead "begin the manufacture of ghosts and establish direct communication with the other world".[11]

Between 22 November and the middle of December, Edison applied an extensive array of experiments to his new force. Some were directed towards excluding electricity as the source of the sparks, Edison concluding that, "these sparks or force . . . do not follow the laws of either voltaic or Static electricity".[12] A further set of tests sought to eliminate electrical induction as the cause, since, in his 22 November notes, Edison had commented that when he had seen similar sparks before he had always attributed them to induction. Removing the iron core from the electromagnet (M in Figure 1) had no effect, Edison noting that he could, "get spark just the same".[13] In other series of experiments he altered the circuit components to determine what effect this had on the etheric force sparks and tested the effect of the sparks on various metals, liquid solutions and powders.[14]

On 24 November, Edison connected the etheric force apparatus to a telegraph line running from his Newark, New Jersey, laboratory to New York and back. When he found he could draw sparks from the return end of this line he concluded, "This force can be transmitted over long telegraph wires [and] may be transmitted over uninsulated iron wires".[15] This entry, like many other records of the etheric force experiments, is in Batchelor's handwriting. It appears that Batchelor was acting as Edison's scribe for he also kept his own notes that, in this instance, contradicted the official laboratory notebook entry. Privately, Batchelor wrote that, "it might be that the force travels across the table instead of

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[8] Ibid., Doc 678.

[9] Karl von Reichenbach (Karl Ludwig Freiherr von Reichenbach) (1788-1869). Reichenbach was a pioneer of German steel production, organic chemistry, mineralogy and the use of antiseptics. In the 1840s he began experimenting on the effects of magnetism on humans, postulating the existence of Odic force. In 1862, seven Berlin professors, including the physicist Heinrich Magnus, published a letter repudiating his Odic theory. For biographical information on Reichenbach see, W V Farrah. "Reichenbach, Karl (or Carl) Ludwig." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie, 18 vols., vol. 11, 359-60. New York: Scribner, 1992. and Karel B Absolon, *Wound Treatment Past to Present: With Reference to Karl V. Reichenbach, Joseph Lister. Louis Pasteur, Alexis Carrel and Others* (Rockville, MD: Kabel Publishers, 1999).

[10] "Etheric Force." *New York Times*, 3 December 1875, 4.

[11] In 1920, Edison claimed to be working on a machine to do exactly that. B C Forbes, "Edison Working on How to Communicate with the Next World," *American Magazine* XC, no. 10 (1920).

[12] Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," TAED NE1691:15. The reason why Edison did not detect electricity is that he was dealing with high frequency alternating current and the tests used were sensitive only to the direct current and static electricity he was familiar with.

[13] Ibid., TAED NE1691:18. Although Edison believed he had eliminated the magnetic fields by removing the iron cores, there was still inductance in the wire spools.

[14] See, for example, Jenkins et al., eds., *TAEB*, Docs 666, 69, 73, 80.

[15] Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," TAED NE1691:17.

going out on the line".[16] For Batchelor's speculation to be true, this experiment would have been evidence of wireless transmission.

There is no evidence of Edison's reaction to criticisms such as those in the *New York Times* but etheric force soon drew attention from a quarter that Edison could not ignore. On 10 December Edison's agent, Norman Miller, wrote inviting him to a meeting with William Orton, president of the telegraph giant, Western Union. Miller's letter concluded:

> I think that you had better bring in a Statement of expenditures and such vouchers as you have ready, also drawings, etc, and any thing that shows work done and progress made. The papers are so full of "new force" that I want you to show that it has not taken up too much of your time.[17]

Edison hoped to secure Western Union's financial backing to establish his purpose-built laboratory at Menlo Park. The implication of Miller's letter was that Western Union might finance Edison to produce inventions of commercial value to them, but not to pursue his questionable new force. Edison must have allayed Orton's concerns, because he signed an agreement with Western Union a few days later (14 December 1875).[18]

Edison acted in the spirit of his agreement and stopped experimenting with etheric force except for one final attempt. On 26 December 1875, Edison's laboratory notebook recorded, "an experiment tried tonight [that] gives a curious result". Figure 2 is the sketch that accompanied the entry.

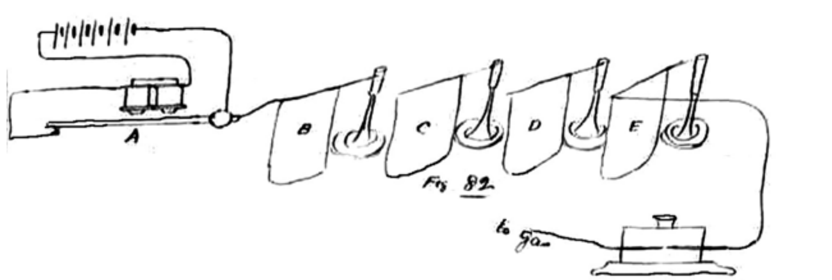

Figure 2 Edison's 26 December 1875 wireless transmission experiment.[19]

The left hand side of the sketch shows the apparatus Edison used on 22 November (Figure 1); B, C, D and E are sheets of tinfoil hung on insulating supports; and the object in the lower right is a darkened box used to observe the sparks.[20] The distance between B and E was 100 inches (2.5 m) and, although there was no wire or other conducting medium between them, Edison noted that they, "received sparks at intervals although insulated by such space".[21] This was, indeed, a curious result. What Edison observed was wireless transmission, confirming Batchelor's speculation of 24 November. Only one word, "curious", hints at the exceptional nature of the result.

Although Edison stopped experimenting on etheric force, criticism of his theory continued. *Scientific American* published a number of negative letters and, in its 5 February edition, reprinted an article from the *Journal of the Franklin Institute* opposing Edison's theory and proposing, as others had done, that the phenomenon could be explained by induction.[22] [23] The author of the article, Edwin Houston,

[16] Charles Batchelor, "Special Collections Series -- Charles Batchelor Collection, Notebooks: Cat. 1317 (1875-1878)," http://edison.rutgers.edu/singldoc.htm, TAEB MBN002:4.

[17] Jenkins et al., eds., *TAEB*, Doc 687.

[18] Ibid., Doc 891.

[19] Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," TAED NE1691:29.

[20] Jenkins et al., eds., *TAEB*, Doc 670. Edison called the darkened box an Etheriscope

[21] Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," TAED NE1691:29.

[22] W E Sawyer. "The "Etheric Force"." *Scientific American*, 15 January 1876, 36. Other letters to *Scientific American* included P H Vander Weyde and "Electron" (5 February), "M B", "A S G" and "C H A" (12 February), "C R H" (26 February) and "S K G" (4 March).

not only disputed Edison's theory, but also implied that Edison was ignorant of current electrical science. Houston's paper stung Edison into responding with a letter demanding that Houston and other critics, "back up their assertions by experiment, and give me an equal chance as a critic".[24] Houston accepted the challenge and with Elihu Thomson, published a more detailed paper in the April 1876 *Journal of the Franklin Institute*, also later reprinted in *Scientific American*.[25]

The second paper continued the derisive tone of the first but this time supported induction claim with a demonstration (Figure 3).

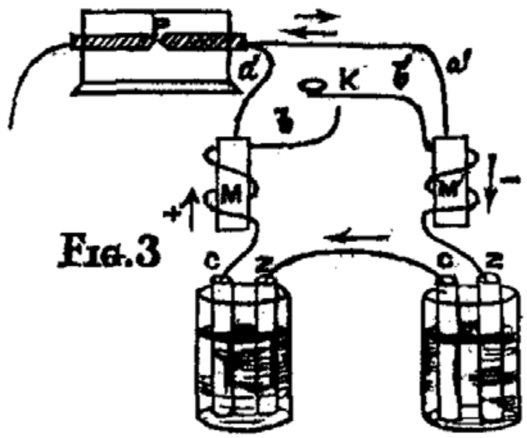

Figure 3 Houston and Thomson's demonstration apparatus. The cylinders at the bottom are batteries, M are induction coils wound in opposite directions, K is a telegraph key and the box in the upper left of the figure enables the sparks to be observed, similar to Edison's Etheriscope.[26]

In their demonstration, Houston and Thomson split the Edison's coil (Figure 1) in two with the cores wound in opposite directions. They claimed this produced two "charges" of opposite polarity that cancelled, preventing the spark from appearing. (Houston and Thomson's device was subsequently understood to be a crude tuned radio circuit. The sparks disappeared because the tuning of the circuit changed.) Houston and Thomson emphasised the need for symmetry of the experimental apparatus, even of the human operator, but did not explain why human beings and other no-conducting, non-magnetic objects should influence electrical induction. (Being a tuned circuit, these altered the tuning in a similar way that a person near the aerial of a radio may alter its tuning.)

Edison did take his turn as a critic in July 1876 but by this time his interest in etheric force had waned through the combined effects of the opposition from his financial backers, his move to Menlo Park and his work on other projects, notably the telephone and acoustic telegraphy. On 24 July 1876, Edison attempted to replicate Houston and Thomson's demonstration, going to considerable effort to reproduce their arrangement and being particularly careful to comply with Houston and Thomson's injunction that it should be well insulated and all parts symmetrical. When at first he found the sparks persisted, Edison wrote derisively that, "the so called polarity experiments of Huston & Thompson were incorrectly made".[27] Edison however persisted, until he eventually found that he could, indeed, make the etheric force sparks disappear at will, while what he believed to be the cause, the opening and closing of the circuit, continued. Eventually he conceded, "So far I think that H & T are

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[23] Edwin J Houston, "Phenomena of Induction," *Journal of the Franklin Institute* 101, no. January (1876).

[24] Jenkins et al., eds., *TAEB*, Doc 726.

[25] Edwin J Houston and Elihu Thomson, "Electrical Phenomena. The Alleged Etheric Force. Test Experiments as to Its Identity with Induced Electricity," *Journal of the Franklin Institute* 101, no. April (1876). The paper was reproduced in the *Scientific American* of 20 May 1876.

[26] Ibid.: 273.

[27] Jenkins et al., eds., *TAEB*, Doc 764.

confirmed".[28] With this concession Edison's etheric force experiments, and his excursion into scientific theory making, were effectively at an end. Edison's actions after this date indicate that he accepted their theory and abandoned his own. Although he dabbled with etheric force several times in the following years, when he eventually turned to work on wireless telegraphy in 1885, he attempted to exploit induction effects and not etheric force.[29]

Edison came to regret this concession when it later became apparent that etheric force was a form of electromagnetic radiation and that his 26 December 1875 experiment demonstrated wireless transmission.[30] In 1910 he observed, "If I had made use of my own work [on etheric force in 1875] I should have had long-distance wireless telegraphy".[31] As Thomas Hughes observes, Edison was constantly looking for such anomalous phenomena as sources of new inventions.[32] In other circumstances, Edison would have seized on his "curious result" as the starting point and quite possibly, given his record, produced successful inventions from it. In this instance, the 24 July rather than 26 December experiment signalled a turning point, an end, rather than a beginning.

The sequence of experiments from 22 November 1875 to 24 July 1876 trace Edison's eight month path from success to failure. In November 1875, at the age of 28, Edison already held 100 patents, was well known to the public and in demand by financiers who saw profit in his inventions. He was only two years from being hailed "The Wizard of Menlo Park" and dining with US President Hayes.[33] [34] In the midst of this success, the etheric force was a spectacular failure, one that damaged his credibility and might have ended his plans for Menlo Park.

3 Science and invention

3.1 Edison the inventor

Edison's 24 July 1876 experiment signalled an end to his etheric force research and the failure of his excursion into science. A key factor in this was Edison's not doing what he did when inventing: he did not instrumentalise failure. Elsewhere I have analysed the processes Edison used to develop one of his most successful inventions, the carbon microphone, a device used in millions of telephones for over a century, noting that when Edison was working on an invention, failure was not something to be avoided, it was something he actively pursued as a means for creating more successful inventions.[35]

A large part of the way he used failure came through what I have described as conceive-build-test sequences, a cyclic process that started with a sketch. One of the most striking features of Edison's laboratory notebooks is the number of new ideas he sketched, sometimes several hundred a month. Edison started a conceive-build-test sequence by sketching several possible arrangements, one or more

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[28] Ibid.

[29] Edison took out patents on a system for signalling between moving trains and stationary wires using induction. It was not particularly effective. Thomas A Edison. *System of Railway Signaling*. US patent 350,234 filed 7 April, 1885, and issued 5 October, 1886. Thomas A Edison. *System of Railway Signaling*. US patent 486,634 filed 7 April, 1885, and issued 22 November, 1892.

[30] The phenomenon that both Edison, and Houston and Thomson, had observed was electromagnetic radiation. The loop of wire in Edison's 22 November experiments was effectively a dipole antenna of the kind used by Hertz to validate Maxwell's theories a decade later. See, for example, Heinrich Hertz, *Electric Waves: Being Researches on the Propagation of Electric Action with Finite Velocity through Space* (New York: Dover, 1962), 108-09.

Edison and Houston and Thomson were far from alone in missing electromagnetic radiation. Others who observed the phenomenon included Joseph Henry and even Luigi Galvani. Charles Süsskind, "Observations of Electromagnetic Wave Radiation before Hertz," *Isis* 55, no. 179 (1964).

[31] Frank Lewis Dyer and Thomas Commerford Martin, "Edison, His Life and Inventions," Harper Brothers, http://www.gutenberg.org/etext/820.

[32] Thomas P Hughes. "Edison's Method." In *Technology at the Turning Point*, edited by William B Pickett, 5-22. San Francisco: San Francisco Press Inc, 1977.

[33] Jenkins et al., eds., *TAEB*, Doc 1277.

[34] Neil Baldwin, *Edison: Inventing the Century* (Chicago: University of Chicago Press, 2001), 98.

[35] Ian Wills, "Instrumentalising Failure: Edison's Invention of the Carbon Microphone," *Annals of Science* 64, no. 3 (2007).

of which were then built tested and the results analysed. The analysis produced three principal kinds of knowledge. Firstly, it identified aspects of the artefact that failed to work as intended. Edison used this knowledge to produce more sketches to be built and tested, repeating the conceive-build-test sequence. Secondly, the analysis of failures under test enabled Edison to identify criteria that a successful artefact should meet. For example, as he was developing the carbon microphone he was also developing an understanding of speech. Unlike Alexander Graham Bell, who was a teacher of the deaf, Edison started work on the telephone knowing nothing about the formation of speech.[36] To develop the carbon microphone Edison also had to develop an understanding of what was required to reproduce articulate speech, inventing his own terminology in the process (such as calling sibilants "hissing sounds"). Edison's artefact development process was thus parallelled by a process of development of a definition of success for the artefact. A third, and rarer, kind of knowledge that came from failures was the identification of anomalous results to be exploited in new inventions through the process described by Hughes. In 1873, Edison devised a carbon rheostat that failed because it was overly sensitive to vibration. In 1877, he used this knowledge of the vibration sensitivity of carbon in his carbon microphone.

Unlike his laboratory notebook entries relating to the carbon microphone, Edison's notes on etheric force contain almost no conceive-build-test sequences. Many days of testing separate the apparatus in Figure 1 and Figure 2 but the etheric force generating instrument is identical. Instead of being prolific in changing the device under test in response to the results, as he did when inventing, Edison was prolific in altering the test conditions applied. Such a focus on exploration of phenomena was not new to Edison and was to recur periodically when he encountered phenomena that could not be handled with his existing knowledge. Edison undertook a similar period of experimentation in 1873-74 when he largely ignored inventing to explore electrical induction after the embarrassing failure, due to induction effects, of a critical demonstration at Greenwich, England.[37] In his etheric force experiments, Edison was building a systematic understanding of the phenomena as he had done in two years earlier with induction. It was potentially useful knowledge but, critically, was not directed towards supporting his public claim to have discovered a new force of nature.

3.2 Varieties of experiment

Steinle has proposed that there exist at least two broad categories of experiments: exploratory experiments and theory-driven experiments.[38] Exploratory experiments involve testing many conditions in a systematic search for regularities (repeatable patterns), usually the outcome of "if-then" questions. The objective of exploratory experiments is to determine which conditions affect the effect being studied, even though, at the time, there may be no related explanatory theory. Edison can be seen doing this as he varied circuit components and tested the effect of etheric force on metals, solutions and powders. Exploratory experiments yield systems of regularities that, in turn, may also lead to postulation of hypotheses. Exploratory experiments, however, represent a broader concept than what have been termed hypothesis-generating experiments because the systems of regularities they yield constitute a distinct kind of knowledge that can be pursued for its own value. In both his 1873-74 induction experiments and his 1875 etheric force experiments, Edison was using an exploratory experiments in the absence of suitable theories to build an understanding of induction and etheric force respectively. For Edison, such systems of empirically derived regularities often took the place of theories, enabling him to produce the predictable results he needed to develop inventions. Reminiscing about Edison's development of the first generator for his electric lighting system, one of his associates, Francis Jehl, described the way in which he applied this kind of knowledge of electromagnetism, "he knew then the modern principles of magnetism, long before they were formulated into the rules we use today".[39]

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[36] It is somewhat ironic that Edison who was deaf himself, should be the inventor of both the carbon microphone and phonograph.

[37] Jenkins et al., eds., *TAEB*, Docs 321-36.

[38] Friedrich Steinle, "Experiments in History and Philosophy of Science," *Perspectives on Science* 10, no. 4 (2002).

[39] Francis Jehl, *Menlo Park Reminiscences: Written in Edison's Restored Menlo Park Laboratory*, vol. 1 (Dearborn, Michigan: Edison Institute, 1937), 141.

If the systems of regularities produced by exploratory experiments lead to a hypothesis or theory, it can be applied in Steinle's second category: theory-driven experiments. This category of experiment is more narrowly focused than exploratory experiments and consequently may involve different methods and instruments from exploratory experiments. Theory-driven experiments are directed towards supporting the theory so, unlike exploratory experiments, they begin with an expected result and are directed towards reducing, rather than expanding, the number of conditions varied, the objective being to reduce the number of conditions to the minimum necessary to produce the effect predicted by the theory. Elimination of unnecessary conditions excludes possible alternative explanations, supporting the theory being promoted. Just as exploratory experiments constitute a broader concept than hypothesis-generating experiments, theory-driven experiments constitute more than what has been termed hypothesis testing experiments. Hypothesis testing is but one of their functions. Theory-driven experiments represent a process of refinement, not only testing of hypotheses.

I propose that theory-driven experiments are directed towards a third experimental type, the demonstration experiment. Unlike the other two, the outcome of the demonstration experiment is known in advance with considerable certainty, usually because the demonstration is the product of a process of theory-directed experimentation. Gooding describes how Faraday developed his little electromagnetic motor through many hours of refinement, then shipped it around Europe where it not only reliably produced the effect that Faraday described but supported his theory on the conversion of electricity into motion.[40]

In the demonstration experiment can be seen a clear convergence of science and invention. For those who saw it in operation, Faraday's motor convincingly supported his theory. Likewise, Edison used demonstrations to convincingly support his inventions. When, on New Years Eve 1879, he demonstrated an electrically lit Menlo Park to the public he was also, by implication, claiming that it demonstrated the validity of the knowledge that went into his invention. That is, it demonstrated that Edison knew how to produce electric lighting.[41] In both science and invention an artefact, the demonstration, is used to support the validity of the underlying epistemological claims. Once a successful demonstration has been produced, particularly if others are able to replicate it, objections tend to focus on *what* knowledge has been demonstrated rather than *whether* it has been demonstrated. Because Edison could demonstrate, and others replicate, the novel qualities of etheric force, the debate became one of what knowledge his demonstrations supported.

3.3 Edison's failure

As I use the term, failure means the inability of something to meet one or more criteria for success. To be a successful artefact, Edison's incandescent lamp (light bulb) had to meet the criterion of producing light from electricity, but had to meet other criteria including lasting for a time that purchasers would accept. Although Edison produced an incandescent lamp almost as soon as he started experimenting, it took well over a year to produce the first lamp that lasted 500 hours.[42] While success criteria may be formally specified (Edison determined that to be technically and economically viable his electric lighting needed to operate at 100 volts) they may also be implicit (for example that users will be able to understand how to operate the artefact). Both success and failure are relative to criteria and dependent on the situation. The criteria can also be applied retrospectively so that Edison's incandescent lamp no longer meets minimum efficiency requirements for many applications, despite still meeting the original criteria of producing light and doing it for a viable length of time.

While Edison's most obvious failure in the etheric force debate was in not convincing others that he had discovered a new force of nature, he failed in two other significant respects. For Edison the inventor, the most significant failure was not developing the curious result of his 26 December 1875 experiment and so, as he acknowledged later, missing the opportunity to develop wireless telegraphy.

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[40] David Gooding, "Mapping Experiment as a Learning Process: How the First Electromagnetic Motor Was Invented.," *Science, Technology and Human Values* 15, no. 2 (1990).

[41] Robert Friedel and Paul Israel, *Edison's Electric Light: Biography of an Invention* (New Brunswick, New Jersey: Rutgers University Press, 1987), 119.

[42] Ibid., 128.

For Edison the scientist, the significant failure was to not develop his etheric force theory beyond an assertion and description of the phenomena. While other factors were at work, notably the opposition of his financial backers, it remains that when he replicated Houston and Thomson's demonstration in July 1876 Edison himself became convinced by their explanation and abandoned his own. Houston and Thomson's success and Edison's failure were the consequence of the choices each made about how to approach science.

The simplest explanation of why Edison was convinced by Houston and Thomson was the superiority of their theory. The difficulty with this is that It is clear from Edison's notes that even part way through the July 1876 replication experiment, he was not convinced by their theory, and for good reason. Edison was an expert on induction effects having experimented extensively with induction in 1873-74 including exploiting reverse currents, the basis of Houston and Thomson's theory.[43] It was not their theory that convinced Edison, it was their demonstration.

An equally unsatisfactory explanation is implied by the rhetorical thrust of Houston's two papers: Edison was merely a tinkerer in science, ignorant of current electrical theories. To accept this is to grossly underestimate Edison. He may have had a limited formal education but he compensated for it by employing well educated experts to give him personal tuition and voraciously read the current scientific literature. Further, he experimented night and day and had one of the best equipped electro-mechanical laboratories in the US. In terms of scientific knowledge, experimental expertise and facilities, he was in no way inferior to Houston and Thomson.

Clearly, more was involved. Carlson points to a broader explanation of the etheric force incident in his biography of Thomson.[44] He attributes Houston and Thomson's success to their exploitation of the unwritten rules of the scientific community and their use of an explanation that drew on accepted theories as opposed to Edison's reference to Reichenbach's marginalised Odic theory.[45] Houston and Thomson were at pains to portray themselves as respectable scientific men while Edison chose the path of populist self-promoter.[46] Houston and Thomson's use of such social structures may have helped convince others but it does not adequately account for Edison's change of mind.

3.4 Science as an artefact creation process

I attribute Houston and Thomson's success at convincing Edison to their creation of two things. Firstly, they proposed a theory built on knowledge that Edison already accepted and secondly, they used theory-driven experimentation to create a demonstration that minimised conditions that could have given rise to alternative explanations. I claim that both are artefacts and that science, like invention, can be viewed as an artefact creation process.

I have described how Edison used exploratory experiments and developed convincing demonstrations when inventing. When he turned to developing a scientific theory, he appears to have erroneously believed that science involved only exploratory experiments. In doing so, he succumbed to the cultural allure of science, which is often publicly portrayed as heroic exploration while privately the scientist in the laboratory does something different, something that is systematic, unspectacular and at times tedious. It is also very close to what Edison, the inventor, was an expert at. Both involve both exploratory experiments and theory-driven experiments directed towards developing demonstrations (although this is obviously not the inventor's only objective). As Steinle notes, published scientific

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[43] For examples of Edison's use of reverse currents see Jenkins et al., eds., *TAEB*, Docs 359, 61.

[44] W Bernard Carlson, *Innovation as a Social Process: Elihu Thomson and the Rise of General Electric, 1870-1900*, Studies in Economic History and Policy (Cambridge ; New York: Cambridge University Press, 1991), 56-65.

[45] Carlson repeats Woodbury's claim that it was Thomson alone, and not Houston, who undertook their etheric force research and devised the apparatus used in the second paper. The evidence is questionable, consisting of Snyder's paper (published 45 years later) and an unpublished note from Thomson to his secretary 60 years after the event. Ibid., 60 footnote 69.

[46] As Pettit has pointed out, the epistemological ascendency of science was still tenuous in this period so scientists sought to distinguish their position, in part, by distancing science from anything that might be tainted with humbug or pseudo-science. By discrediting the upstart Edison (and, by association, Reichenbach), Houston and Thomson bolstered the prestige of science by distinguishing it from pseudo-science, and, in the process, enhanced their own prestige. Michael Pettit, "The Joy in Believing: The Cardiff Giant, Commercial Deceptions, and Styles of Observation in Gilded Age America.," *Isis* 97, no. 4 (2006).

accounts for the most part omit descriptions of exploratory experiments and failures. The experimenters involved even find it difficult to recall why past difficulties were, indeed, difficulties.[47] In the light of this, Edison's belief that science was different from invention is understandable. He approached science based on its public image, emphasising exploration and neglecting the processes needed to produce a convincing argument. His view was erroneous, not because it fundamentally wrong, but because it was too narrow.

As a consequence of this narrow view, Edison's characteristic conceive-build-test sequences are absent from his etheric force experiments as evidenced by his last, 26 December 1875, experiment using the same apparatus as his first. Instead, his notebooks are characterised by exploratory experiments, an understandable approach given Edison's belief that he was dealing with an, "entirely unknown force, subject to laws different from those of heat, light, electricity or magnetism".[48] His notebooks show Edison accumulating more phenomena and regularities in a systematic way through series of grouped tests. Crucially, Edison put almost no effort into developing his theory beyond that announced to the press at the end of November. As a consequence he did not use failure analysis to seek its weaknesses and so seek to strengthen the theory, nor did he develop a clear set of criteria his theory needed to meet to be successful. Significantly, although he seems to have convinced himself that etheric force sparks were not due to induction, he did not develop a theory to show why induction was not a valid explanation or a demonstration to support his argument. Consequently, he provided no better demonstration to counter the induction argument than repeating the few tests he devised on 24 November 1874, two days after first observing etheric force.[49]

In contrast to Edison's concentration on exploration, Houston and Thomson neglected it in favour of developing their theory and demonstration. Snyder described the young Thomson (he was 22) excitedly running through their school building, drawing sparks from all manner of metal objects. Despite this remarkable observation, Houston and Thomson failed to explore how induction, which was previously observed to act at very short range (less than a metre), could cause sparks at such great distances. [50] In not exploring this, Houston and Thomson, like Edison, missed the opportunity to pioneer wireless. Instead, they chose to work with the experimental approach needed to convince others, the part to which scientists' published accounts are directed**.**

The crucial error for Edison was to not instrumentalise failure to the extent that was his custom when inventing. In contrast, when Houston's first paper did not silence Edison, Houston identified its weaknesses and used this knowledge to construct a second, stronger, paper with Thomson. In particular they addressed Edison's criticism that while he had demonstrated etheric force, Houston and Thomson offered no experimental evidence for others to test.

Although he was more than capable of doing so, Edison failed to produce a demonstration equivalent to Houston and Thomson's to show that etheric force was not induction. Instead, his demonstrations concentrated on the more bizarre aspects of etheric force, an approach that may have amazed his audience but clearly did not convince many. Edison's demonstrations supported his claims about the phenomena but not his theory. Because Edison produced no demonstration to support his theory, Houston and Thomson's demonstration not only supported theirs, but became a de facto criterion for success. In the absence of a counter demonstration from Edison, theirs filled the vacuum and was even more convincing.

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[47] Steinle, "Experiments in History and Philosophy of Science," 423.

This highlights the value of using notebooks, such as Edison's, rather than respective accounts as a basis for studying research processes. The notebooks may be filled with dead ends, blank pages, trivia, doodles, and the apparently inconsequential, but they reveal what was being done and thought at the time, free of reinterpretation than comes when the future is known.

[48] Jenkins et al., eds., *TAEB*, Doc 678.

[49] Edison, "Notebook Series -- Experimental Researches: Cat. 994 Vol. 1 (1875-1876, 1877-1878)," TAED NE1691:18.

[50] Monroe B Snyder, "Professor Elihu Thomson's Early Experimental Discovery of the Maxwell Electro-Magnetic Waves," *General Electric Review* XXIII, no. 3 (1920).

4 Conclusion

Edison failed in his attempt to advance his claim that he had discovered a new force of nature, not so much because of defects in his theory, but because he succumbed to a cultural myth of science, a myth that portrays science as fundamentally different from inventing. In accepting the myth he acted as though science required him to do something different experimentally from what he customarily did. Had he reflected on the history of science he would have seen long and rich list of scientists who were also inventors including Galileo, Newton and his own hero, Faraday. That they did both should not have come as a surprise to Edison since they would have used the same processes to create physical artefacts, like inventions, as they did when creating their theories and demonstrations.

At the most fundamental level Edison failed because he saw science only as exploration. By 1891 he had reversed his view, a Chicago newspaper quoting him as saying, "There is as much difference between an inventor and a scientist as there is between an explorer and a geographer . . . Of course scientists may be inventors and inventors may be scientists. And explorers may write geographies, but they seldom do. The inventor discovers things and then the scientist steps in and tells or tries to tell what it is that has been discovered."[51] The etheric force incident suggests that in 1875 Edison believed that it was the scientist who was the explorer. In 1891 had acknowledged that inventing required an explorer's drive and skill, and that involved exploiting the paradox that to succeed, inventors needed to pursue and exploit failure.

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[51] Chicago Daily Globe. "Arrival of Thomas A. Edison." *Chicago Daily Globe*, 13 May 1891.