Technological discussions in iron and steel, 1871-1885

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Abstract

Before 1870, most North American iron was locally produced. By 1885, most U.S.-made iron and steel came from large plants operating new high-volume production processes. Starting in 1871, *Transactions of the American Institute of Mining Engineers* (TAIME), a professional engineering journal, published papers which discussed changes in iron and steel making, mining, engineering, and management. We make inferences from TAIME articles from 1871 to 1885 on several general questions to help formulate the ways in which episodes of new technology are similar: Does the discussion about the rising *technological* paradigms of Big Steel fit Kuhn's hypotheses about the discussion of *scientific* paradigms? Is there evidence of quantitative changes in technological uncertainty evident in the texts? Does the open technological discussion parallel open-source software development?

Introduction

People who work to advance a technological frontier have an interest in communicating with others who work on related problems. Specialized forms of communication help them all discover and adjust to change. Some aspects of these communications have been judged to be similar across episodes of radical technological change such as the invention of the airplane, the invention of the microcomputer, open source software development, and the advance of iron and steel technology in the second industrial revolution period (Meyer, 2003). Kuhn (1962) defined scientific revolutions and how communication flows change over time as new scientific paradigms appear. We investigate here whether the communications flows in a kind of technological, organizational revolution, have the qualities Kuhn attributes to scientific communications. A technological revolution might be like a scientific revolution in this way.

We analyze publications during the development of the mass steel production industry in the U.S. in the 1870s and 1880s, as seen in the *Transactions of the American Institute of Mining Engineers* (TAIME) and its parent weekly *Engineering and Mining Journal* (EMJ). Big Steel was a new "technological paradigm." The free and rapid transfer of detailed technical information enabled the 19th century iron industry to work collaboratively to create Big Steel just as the free and open sharing of code enabled the Internet to develop in the 20th century.

We try statistical tests of Kuhn's propositions about pre-paradigmatic versus paradigmatic literatures. Moreover, like the semiconductor/computer/software revolution, we see layers of improving technologies in the dawning age of steel. The technologies for making steel were complex and interrelated: one invention or improvement could not be made without a series of inventions and improvements that preceded it. One example is the improving compasses used to find magnetic iron ore. We find that in this time of great technological expansion, information and knowledge is shared widely, but the statistical tests do not support the proposition that there is a paradigm shift in this period.

Background

The American Institute of Mining Engineers (AIME) began to develop in a time period of rapid expansion of knowledge regarding the making of steel. By 1870, anthracite coal had been used in combination with a hot blast that greatly increased the output of pig iron beyond any previous output. The United States was still reliant on imports from Great Britain for its rapidly expanding rail system, and the iron industry was greatly interested in finding a way to make their own steel. Not only were there great profits to be made, but the country was increasingly connected by a network of railroads and telegraphs that made increased communication possible. AIME was one of several such associations that blossomed during this time period. The American Iron and Steel Institute was another. The AIME was founded by circulating a letter in 1871 and the first meeting proceedings and papers were printed in the *Engineering and Mining*

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[1] Views expressed in this paper are those of the authors and do not reflect official policies or measurements of the U.S. Bureau of Labor Statistics.

Journal. As AIME developed and gained a large membership, the proceedings of the meetings were then published in a more permanent form, the *Transactions of the American Institute of Mining Engineers*, or TAIME. TAIME was hard-bound and widely distributed.

The introduction of the Bessemer steel-making process offered a way to make more reliable, longer-lasting rails which could hold heavier trains. By 1876 it had been attempted in fifteen plants in the United States (Swank, 1883). Industrial processes were being developed at the same time (in the iron sector and outside it) to work more closely doing complex work in groups rather than by individuals conducting well-defined craft work by earlier definitions of "craft." The TAIME was a leading venue for discussing how to make higher-quality steel rails.

In the Carnegie company, there was "a rivalry of great furnaces" that expresses rapid growth during this time period: "Isabella No. 1" competed with "Lucy" in a friendly competition that increased their output from 350 tons of pig-iron per week in 1872 to 500 in 1873, 800 in 1878 and then 1,000 in 1881 (Bridge 56 England's supremacy in iron and steel was at an end by 1890 (Swank, 1892, p. 377).

Economic and labor historians have often described this change, from the worker's point of view, as "technological deskilling" (Nuwer 815). The assumption has been that "craft skills provided workers independence" and that, with the advent of more complex industrial processes, individuals no longer mattered and thus workers lost power over their environment" (Nuwer 815). However, the main point to his article is that "the integration of these tasks into a continuous-flow production process heightened the need for cooperation among workers. Continuous production necessitated that the tenders of machines diagnose bottlenecks and make appropriate adjustments . . . . [and] Supervisors attempting to coordinate operations relied on the workmen's attentiveness to process flows" (837). It became a complex interchange of information during the work process where each worker had to know what went before his part of the process and what came after it and any danger signs that may occur along the way and think of potential solutions as well. Worker's independence was replaced by dependence on cooperation.

Similarly, the knowledge about how to create and improve these processes was itself a collaborative information-sharing process. Nuwer writes about the "diffusion of steelmaking technologies," recognizing that they were not reinvented, but shared.

American Institute of Mining Engineers – AIME

AIME was founded by three mining engineers – Eckley B. Coxe, R. P. Rothwell and Martin Coryell. They began the organization by sending out a circular, published in several periodicals and mailed, which read, in part, as follows:

> In European countries, where the arts of mining and metallurgy have long been the subject of the most careful study, no means have been found so effectual in attaining the end above proposed, as the free interchange of experience among those actually engaged in these industries; and this object has been accomplished mainly through the medium of "Institutes," "Associations," or "Societies," composed of those engaged in these occupations, and by the periodical publication of "essays" of "papers" communicated to such societies by their members.

Thus, the founders of AIME based the structure of their association on the model of scientific and technological associations in Europe. Their aim, from the beginning, was to hold meetings, visit competitors' sites, read papers and then publish the papers so that they could be widely distributed. The goal was to "consult for mutual advantages upon the difficulties encountered by each . . ." (Vol. 1, p. 3). The two objectives of AIME were "The more economical production of the useful minerals and metals [and] The greater safety and welfare of those employed in these industries" (Vol. 1, p. 3). They sought owners of works, engineers, or foremen as members.[2] Men were encouraged to bring their wives[3]. The first meeting of 22 men was held in Wilkes-Barre, Pa., on May 16, 1871. Each meeting consisted of visits to industrial sites, the reading of papers and other social events. After this meeting there were 71 members.[4] During the first meeting in May, 1871, they wrote the rules and read five papers, three of which were published in the first Volume. Membership increased by about 100 per year (Alford 243).

In his history of the AIME in the 1971 Centennial Volume, Alford wrote that "in the early days of the Institute, there was little distinction among the field of work in AIME, and

[2] EMJ, May 9, 1871., "The American Institute of Mining Engineers," p. 297

[3] Although there are almost no references to women in AIME, TAIME or EMJ, evidence exists that women participated. The evidence for this particular statement is in the *Report of the Committee of Five upon the Condition of the American Institute of Mining Engineers*, published by AIME in New York in 1912. It lists attendance at nine meetings in which the number of "Ladies" is approximately equal to the number of "Members" and "Non-Members," p. 6.

[4] Joe B. Alford, "History of the Institute: One Hundred Years of AIME," *Centennial Volume American Institute of Mining, Metallurgical, and Petroleum Engineers 1871-1970*, New York: American Institute of Mining, Metallurgical, and Petroleum Engineers, 1971, p. 240.

every member was more or less interested in what other members did" (Alford, p. 242). The papers covered the following topics (among others): Geology, Chemistry, Physics, Mining Exploration, Metal Mining, Metallurgy in Nonferrous Metals, Iron and Steel-making, Industrial Minerals, Petroleum Drilling, Production and Refining (replace this section with a selection from our time period and make a count of the safety articles here as well). "Thus the precedent of cooperation and mutual knowledge, over and above the burgeoning diversity and specialization both among and within societies, provided a background for the great increase in specialization that later years would bring" (Alford 244).

Engineering and Mining Journal – EMJ

AIME use a weekly newspaper, The Engineering and Mining Journal, first as a method whereby to gather members, then as a voice to relay the proceedings of meetings, including papers, and finally as their official "organ" for disseminating material. There were many weekly journals on this subject during the time period – *Iron Age*, *Iron Trade Review*, *Iron* – as well as journals on related subjects. They served slightly different areas and constituencies and all of them evolved during their lifetimes from name to name as their focuses shifted and the technological environment changed. For instance, *EMJ* started in 1866 as the *American journal of mining, milling, oil-boring, geology, mineralogy, metallurgy, chemistry, etc.* At that stage it was largely about the deposits of gold and silver in the American west. It also reported on scientific meetings and published papers specifically written for the journal. When Rossiter W. Raymond, the eventual secretary of TAIME, took over the editorship in 1868 ant the title evolved to the *Engineering and Mining Journal* by July of 1869.

All along, the journal published packets of information about a variety of topics, including reports on mining activities from every region of the country (that arrived by steamship), notes on inventions, poems, patents pending, brief discussions of geology, machinery, chemistry, prices for coal, securities, gold and other minerals, and advertisements and filler. The School of Mines as Columbia College had just started (and its syllabus was printed in this and subsequent issues) and an American Bureau of Mines was incorporated in New York State (Vol. 1, #2, April 7, 1866, p. 24). As the issues progressed, other schools opened and advertised their courses, including a mining department at Yale (v. 1 # 18, p. 285, July 28, 1866). There was a section called "All Sorts" that was full of quips like "The emigration of squirrels westward, which was noticed all over the State of Michigan a short time ago, is now being followed by a migration of bears" and Molly Molasses is the name of an Indian woman an hundred years old, who is still weaving baskets at Belfast, Maine" (Vol. 2, #1, Sept. 29, 1866, p. 13).

They also published the proceedings of scientific meetings. Since they were headquartered in New York City, they began to regularly publish transcriptions of the discussions of the "Polytechnic Club of the American Institute," a group of inventors who met monthly at Cooper Union in New York City to discuss their inventions. The habit of transcribing discussion was interesting. It can be seen in many of the journals of the time as well as in the published proceedings of the meetings. In one issue of EMJ, the editor wrote: "It has long been the opinion of those familiar with the transactions of the Institute that the discussions which follow the reading of papers are frequently more valuable than the papers themselves" (EMJ, V. 12 #13, Sept. 26, 1871, p. 195.). Written transcriptions were the only way to record conversations.

In 1872 EMJ became the official "organ" of the association: in the section called "Publisher's Announcement" they added a section that begins "It is the Organ of the American Institute of Mining Engineers, and is regularly received and read by all the members and associates of that large and powerful society, the only one of the kind in this country." Other members of the group joined Raymond as editor: first Willard P. Ward, John A. Church and Richard P. Rothwell. This series was 16 pages long with illustrations of mines and new machinery, proceedings from the AIME meetings (which included transcriptions of conversations), statistics on the production of blast furnaces and the prices of coal, an iron market review, some stock market information, notes on import duties, descriptions of accidents, reviews of new publications, correspondence, notes on the iron trades abroad, and five pages of advertisements. The policy which had begun with the first series in 1866, of reporting on patents was dropped (perhaps there were too many and they were too complex?).

The articles in TAIME were first published in EMJ and read at the meetings. This was not a hard-and-fast rule: not all articles published were first published in EMJ or read at a meeting: exceptions were made for foreign members and some others as well. When the papers were published in EMJ, they often were serialized across several issues. Some of the papers were written as speeches and later published in TAIME with the exact same text (included references to “this evening,” the hour when the paper was being read), such as “The Economy of the Blast Furnace” by Professor Frederick Prime, Jr. (V. 12, #24, Dec., 12, 1871).

Towards the end of the time period in question, EMJ lost much of its informal and entertaining flavor. The small sections declines, patents were dropped, there was no filler, and the articles became longer, running in blocks of small print from page to page. The layout became less accessible to the general reader

Transactions of the American Institute of Mining Engineers – TAIME

A guiding spirit for both EMJ and TAIME was Rossiter W. Raymond. He was the president for three terms and then became the secretary of AIME, a position which he held for 27 years, from 1884-1911. Raymond solicited and edited papers, eventually with the assistance of Mrs. Henry Stevens Conant.[5] Alford comments on the diversity of his knowledge: “His familiarity with all phases of the industry at that time stemmed from this earlier position as U. S. Commissioner of Mining Statistics from 1868 to 1876, during which time he made repeated visits to western mining districts and observed techniques of geology, mine operations and ore treatment” (Alford, p. 242). Alford says that the Transactions “were generally considered to constitute the most extensive and authoritative library extant on engineering and technology in the mineral industry” (p. 243). Raymond wrote the charter. Raymond himself was a kind of information broker or moderator of the whole networked enterprise of advancing iron and steel technology.[6]

TAIME was published once per year and the publication usually lagged behind the meeting date by at least a year. The differences between the proceedings and papers in EMJ and TAIME were the differences between a fast and immediate form of communication and a secure repository for it. Things that were omitted from TAIME: one-line contributions to discussions. EMJ more an actual transcription of events as they took place, sequential, in time. TAIME rewrites times somewhat, as in the case where it says “At the conclusion of the discussion on Mr. Rothwell's paper, a committee was appointed” when in fact it happened the next day, (TAIME,

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[5] The only reference to Mrs. Helen Stevens Conant is in the 28th volume of TAIME from 1898 when she died. Raymond writes: “No one but myself will ever know how much of the credit universally given to our *Transactions* for exceptional freedom from errors of the pen or the press was due to this patient and skillful work at my side,” p. iii. She was also an author of books and wrote frequently for *Harper’s New Monthly Magazine*.

[6] As such his role had analogues in other episodes to Alexander Holley, Octave Chanute, Lee Felsenstein, and many open-source programmers.

Vol. 1, p. 9; EMJ, May 30, 1871, p. 338). In EMJ there are actual transcriptions of discussion that took place during the meeting that are largely omitted in TAIME. In TAIME, however, there are things that do not occur in EMJ. For instance, there is formal thanks to the hosts in a formalized format.

> Resolved, That the thanks of the Institute be tendered to the owners, operators, superintendents, and other officers of mines and works in the neighborhood of Wilkes-Barre . . . for their unwearied attention to the entertainment and instruction of visitors, and also to the Lehigh Valley, and Lehigh and Susquehanna Railroad Companies, for facilities extended to members traveling over their lines (Vol. 1,p. 9).

The content in the papers is largely unchanged. Thus, the two journals served different purposes: EMJ distributed the proceedings of the meetings and the content of the paper, with typos and mistakes but also with immediacy, to a large group of interested parties. It was a reflection of real happenings and followed the format of the happenings, describing them as they occurred, including formal conversations in the meetings and papers. EMJ was on the table directly after the meeting, with the articles in small doses so that they were easier to read with breakfast. EMJ would stay open by itself. TAIME, a thick and heavy book, was required a different situation to read (a fireplace, for instance). TAIME functioned as a summary of this information. EMJ was a bridge between the spoken world of knowledge exchange and TAIME represented codified knowledge in a permanent form. EMJ was ephemeral but TAIME however, has longevity.

The text data, and article and author databases

A nonprofit contractor, Digital Divide Data (DDD), scanned photocopies of pages of the *Transactions* journal. Images of the pages were then cropped and cleaned up in the Photoshop software. Tables, pictures, diagrams and some equations were copied elsewhere as images. DDD then ran a optical character recognition (OCR) software on the text, and a spell check on the results. Most of this labor-intensive work was done in Cambodia.

The resulting PDF files include text with font and format information, so they are re-rendered to resemble the original pages although the text does not look exactly the same. On each page the images have been pasted back in. The overall size of these fourteen years of documents was about 5600 pages in the originals. The reason to store the contents as text (not just as an image of bits) is that the resulting PDFs are searchable for particular words. The PDFs of the journals are now online at http://econterms.net/pbmeyer/research/ironwork/TAIME.

We have created a spreadsheet of information about the papers. There is a row for each of 712 articles in *Transactions* in this period. (There were another 40 or so which are not yet scanned and therefore not yet coded.) Each record has the title of the article, author(s), date, topic, length, and presence or absence of citations. We have summarized and taken notes on a number of the articles. We have word counts of each article, and counts of certain topical terms such as "mining", "anthracite", and "Bessemer", and other terms meant to detect technological uncertainty in context; terms like "uncertainty", "risk", "doubt", "perfection". By searching and recording the frequency of expressions of uncertainty in the articles concerning the iron and steel industry, we attempt to categorize the environment of discourse.

We have a second database of the authors, with their names, publications by TAIME volume, and when possible more information. For some we have some mix of birth date, death date, educational level, professional role, and areas of professional expertise, and biographical notes. We collected this information from a variety of sources, and there are more sources not yet tapped.

The purpose of this detailed organizing of the data (which is a long project, not complete) is to attempt to establish whether some hypotheses about this technical discussion are confirmed in this data, to help a scientific understanding of technological advances come about. One hypothesis about scientific literatures, from Thomas Kuhn, is that articles become shorter over time as paradigms and their known vocabularies become established and standardized. We look at whether this is true for this period of technological change. A second hypothesis follows from evidence that there was more economic noise and uncertainty in the environment of the iron and steel industry than other industries, presumably because of technological change there (Meyer, 2005). A third hypothesis is that periods of sharp measured productivity growth follow from layers of improving technologies which improve over time, not just one improvement or one sequence of improvements to one layer.

Kuhnian Hypotheses of Pre-Paradigmatic and Paradigmatic Literature

To characterize scientific revolutions, Kuhn (1962) defined a kind of transition associated with the appearance of a new *paradigm*. A paradigm is a set of concepts, tools, measurement techniques, natural laws, and terminology which some group of scientists has committed to. They take these elements of the paradigm to be mutually consistent, relevant, and to be a useful set of beliefs and interpretations for understanding natural phenomena. A new paradigm will tend not to be commensurate – that is, it requires different measurements and interpretations than a previous paradigm; they do not compete on a level playing field. A new paradigm will tend to make more precise and accurate predictions than earlier paradigms, and if the new paradigm survives in scientific discussion, this seems to be one reason it does – the additional precision is useful, or persuasive for some other reason. One example of a new paradigm is Einstein's theory of general relativity.

We are exploring whether some aspects of the paradigm concept are portable to technological revolutions. A new technology is closely associated with changes in what tools are relevant. In the case of the rise of Bessemer steel, we also see significant changes in the workplaces including how they were organized. More and more equipment was involved, and the pace of work sped up. More scientific knowledge was necessary to design and improve the equipment than previously.

Kuhn (1962) made a couple of generalizations about how written scientific communications evolve change from the time before there is a paradigm, and afterward. Kuhn predicted that before a paradigm is clearly established and well known to the scientists doing work in a relevant field, the authors are likely to write longer articles, in which they define their concepts and tools at some length, and do not assume the reader is familiar with them, or perhaps assume readers are familiar but must be persuaded. After a paradigm is established, Kuhn expects that articles would be shorter, and take more as assumed.

We test whether articles on iron and steel topics were longer than those which were not – e.g., because they were about mining. Articles in established paradigms should have more references to previous work. We think articles in pre-paradigmatic, or uncertain, areas are more likely to cite the author's personal experience, and will test this if possible by whether the authors use "I" or refer directly to named persons or personal experiences.

Kuhn posited that in a pre-paradigmatic phase a scientific field includes people with a wide variety of educational backgrounds. This narrows once a paradigm is established, and education in that paradigm becomes sharply defined and is taken to be a prerequisite of work in the field. Therefore we are gathering educational information about those who published. Some articles were written by experienced iron managers or engineers, some of whom had not reached high school. Others had PhD's in scientific fields, including professors and some consultants. This diversity in occupation and education suggests a kind of pre-paradigmatic look to the population which we attempt to quantify.

Kuhn hypothesized that the early authors of a new paradigm are younger than the authors in established paradigms, for a series of interrelated reasons which include their incentives. The young authors have less to lose and more to gain by trying something radically new, whereas older authors have a comparative advantage in prestige, legitimacy, and experience. We have collected biographical information about the authors but do not have enough ages and other information yet to test this proposition statistically.

Expressions of Technological Uncertainty in TAIME

In order to track expressions of uncertainty in the volumes of TAIME, we counted various words that could express uncertainty. Examples are in the next table. In the end only a few of these could be compared over time. Some did not occur enough, or the meanings in context were too varied for a count over time to have a neatly interpretable meaning. In the table are candidate words.

?	definite	inquiries	question (s, ed, ing, able)
ambiguity	difficult	inquiry	resolve (s, d, ing)
answer (s, ed, ing)	dispute (s, un)	investigate (s, ed, ing)	right
argument (s)	doubt (s, ful, fullness, less, lessly)	know (un, n. ledge)	risk (s, ed)
ask (s, ed, ing)	error (s)	opinion (s)	test
belief (s)	evidence	perhaps	true
certain (ty)	experiment (s, al, ing)	probability	trust (dis, mis, s)
chance	if	problem (s)	truth (s)
confusion	inquire (d, ing)	query	(un) certain (ty)
criticism			

Uncert(ain, ainty)	valid (ity)	whether	wrong

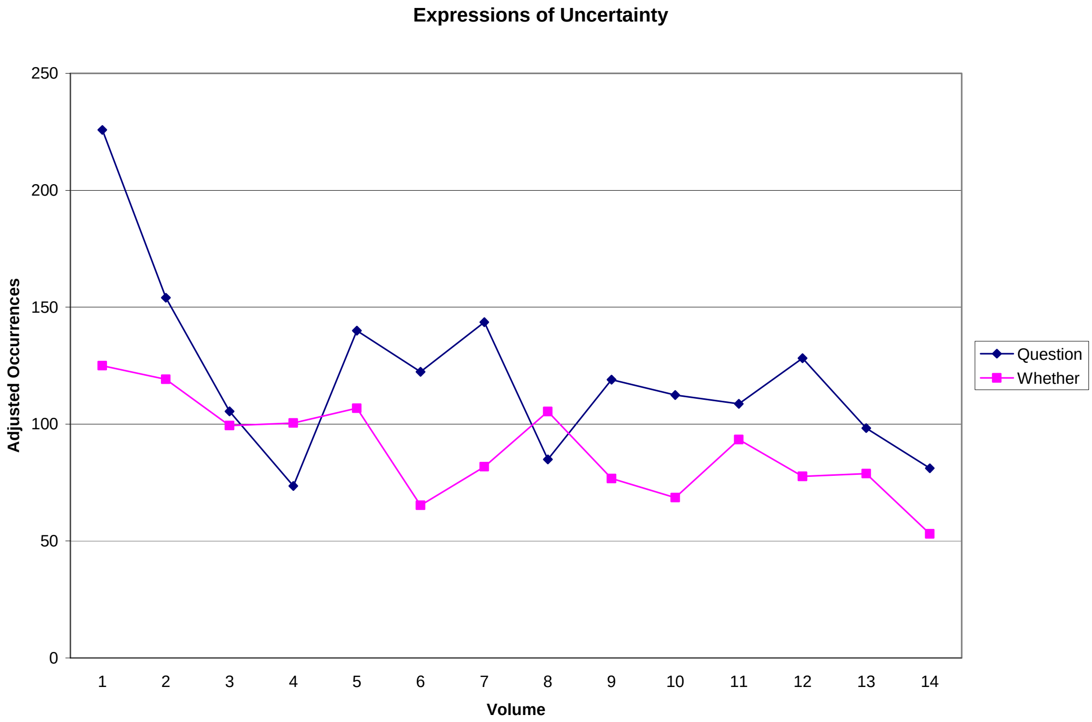
I (author Johnson) counted some of these words in the papers in the annual volumes, and also the discussions and footnotes, excluding the tables of content, meeting proceedings, organization rules, headings, tables, and index. This led to much pruning of the list and the source materials too.

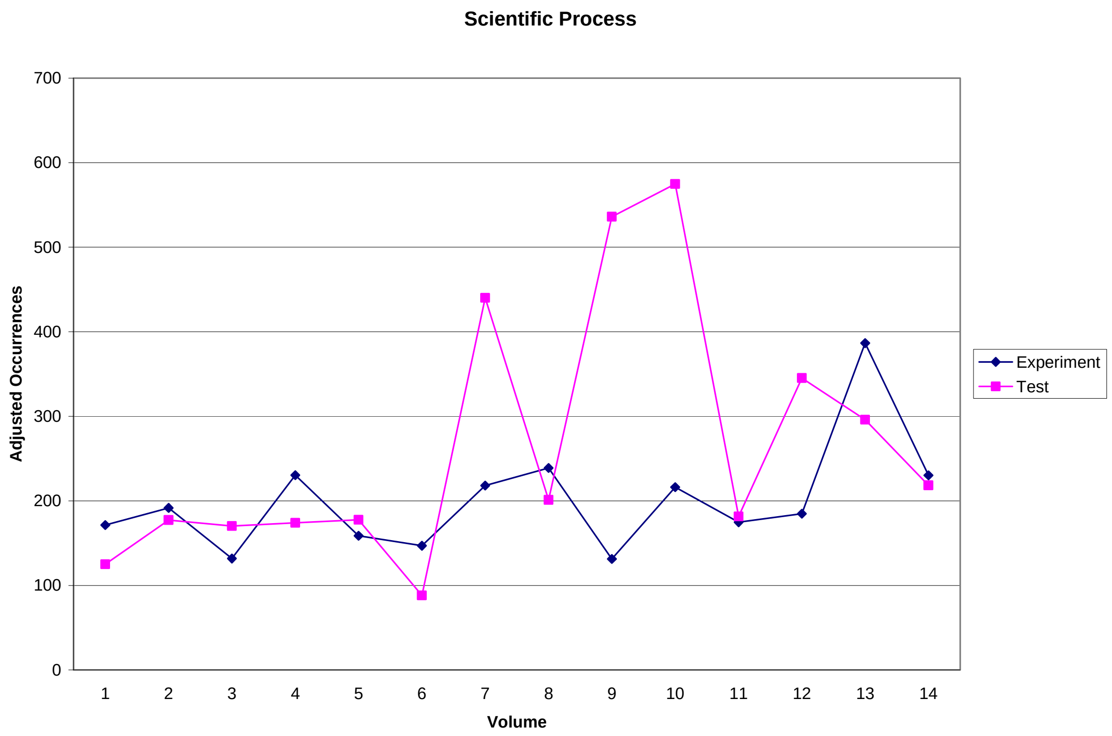
The question mark might have been a good indicator, but it appeared too frequently in some volumes because of errors in the optical character recognition. “Answer” occurred too frequently in the meaning of “to fulfill” or serve, i.e. “It **answer**s the cause of . . .” “Ask” occurred only within the context of the discussions and was largely absent in the papers. “Confusion,” “evidence,” and “(un)certain(ty)” occurred too infrequently. That left me with “question,” “whether,” “experiment,” and “test.” Counts are below in the next table.

One article had to be excluded. The counts from “The Law of the Apex,” in both an article and an appendix, are omitted. It’s an article about a legal issue that contains the reprints of legal documents and they contain and extraordinary number of instances of “whether” and “question” which must be specific to legal language. The original count of Whether was 110, instances in the Apex articles were 47, so I am using the total of 63. The original count for Question was 150, the instances in the Apex articles were 46, so I am using the total 104.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
#of Pages.	496	344	493	408	693	613	550	636	899	569	589	811	926	678
Question	112	53	52	30	97	75	79	54	107	64	64	104*	91	55
Whether	62	41	49	41	74	40	45	67	69	39	55	63*	73	36
Experiment	85	66	65	94	110	90	120	152	118	123	103	150	358	156
Test	62	61	84	71	123	54	242	128	482	327	107	280	274	148

Two expressions of uncertainty, the use of question and whether (which linguistically signifies a question) declined over the time-period we are studying and the use of experiment and text rose (see graphs below). This corresponds to the trend within the industry away from listening only to men with experience, and toward scientific inquiry, the use of chemistry, and formally educated staff and more formally conducted experiments.





These volumes signal changes change in the way things were done in the American iron industry. Corporate research and development was appearing. However this was a turbulent transition in which much was ambiguous. Telling the history of his industry's recent past in a presidential address, Bayles (1884, p. 20) wrote:

> When the influence of our technical schools began to be felt, ... the laboratory began to be recognized as an essential part of an iron or steel-making plant, and in nearly every establishment with any pretensions to completeness, the chemist has become an important member of the staff. But it was not more than fourteen years ago, that this was the exception rather than the rule.

Bayles offered two key quotes to show that as of 1872, there was a real variation of opinion about whether chemists, examining the input materials, could help quickly enough to be useful in a production process. Bayles quotes a general manager of an iron works having written to him an uneducated opinion in 1872:

> The president of our company thinks we ought to follow the fashion and have a chemist. To my mind it is a waste of money. When I want an analysis I can have it made – and that is very seldom; for the furnace manager who needs a chemist to tell him the quality of ore or limestone,

> or whether his pig-iron is soft or hard, had better resign and go to farming. However, if the president says chemist, chemist it is. My object in writing is to know if you can recommend a young man competent to fit up a laboratory and take charge of it. . . . [It] is desirable that he should be a gentleman. My wife plays the piano and I do a little on the flute; and if we can get a chemist who plays the violin, we could have some music evenings. If you can suggest a man who combines these qualifications, I could employ him. I do not know what a chemist would expect; but I should not care to pay more than $10 a week.

The manager does not know what a chemist expects to be paid. There may be no established labor market for chemists, or if there is, this manager is unfamiliar with it. Bayles gives this example to illustrate how much has been learned since this mistaken letter. This is a sign of novelty and uncertainty – an important paradigm is appearing, and this manager seems not to even recognize it. But Bayles acknowledges that there later was a subsequent overreaction, toward chemistry, when in fact physical tests turned out also to be necessary to determine high quality output. These waves and differences of opinion are evidence of social uncertainty about steel making.

This longstanding perspective, that lab chemistry was irrelevant, was about to be wiped out. Some people understood that. Bayles quotes Andrew Carnegie about the same time:

> We found . . . a learned German, Dr. Fricke, and great secrets did the doctor open up to us. [Iron ore] from mines that had a high reputation was found to contain ten, fifteen, and even twenty per cent less iron than it had been credited with. Mines that hitherto had a poor reputation we found to be now yielding superior ore. . . . [T]he uncertainties of pig iron making were dispelled under the burning sun of chemical knowledge.
> What fools we had been! But then there was this consolation: we were not as great fools as our competitors. . . . Years after we had taken chemistry to guide us [they] said they could not afford to employ a chemist. Had they known the truth then, they would have known they could not afford to be without one.[7]

Carnegie's view was overly optimistic but he had identified a basic truth. The rules had changed. Adaptation to the new situation now seemed to *require* academically-trained experts.[8] But before 1872, only a few early adopters had hired chemists.[9]

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[7] Livesay, 2000, p. 126.

[8] In the recent period this is better understood. Bartel and Lichtenberg (1987) looked for implications of the assumption that "when a new product or process has been recently introduced, there is 'more (remaining) to be learned' about the technology, and there is a greater premium on the superior 'signal-extraction' capability of educated labor." They reported empirical results in which the introduction of new technology (measured by the introduction of new equipment) correlates with relative demand for educated workers, and that this difference was seen more strongly in R&D-intensive industries.

We attempted to use another set of definitions of articles relevant to steel. We count the number of uses in each article of these iron- or steel-related phrases: "hot blast", "Bessemer", "puddling", "open hearth", "Siemens", "Martin", "spiegel", and divide this count by the total number of words in the article. This frequency is a proxy for the iron-relevance of the article. We compute also the ratio of the use of the string "uncert", representing relevance of literal uncertainty. These counts across the 712 articles have a correlation coefficient of .0071. So the articles with iron-related terms are slightly more likely to use words with "uncert" with them than other articles are, by this metric. We can also show that the word count of an article is slightly positively correlated with the year the article was published (correlation of .033), so articles tended to be a little longer in the later years. Interestingly the incidence of the iron-related terms, and of the "uncert" terms, decreased slightly over time. (That is, the correlation of the frequency of these terms with the year is slightly negative.) Iron-related terms were declining in frequency in TAIME although the iron sector was expanding as a fraction of the economy at large. We can speculate as to why. Perhaps this was because with the rise of corporate research and development, more of the iron texts were not published in open publications like TAIME.

The Union of Science and Art

An 1876 issue of TAIME contains a presidential opening address by A. L. Holley entitled “The Inadequate Union of Engineering Science and Art” (p. 191). He talks there about how the practical man has a sensory knowledge of the many variables at play during the steelmaking process, whereas the newly-trained scientist has not even witnessed these processes. Here is a sample sentence (stylistically florid, typical of the time period, and rich with examples):

> The consciousness of a certain jarring of the foot-plate, a chattering of a valve-stem, a halt in the exhaust, a peculiar smell of burning, a sudden pounding of the piston, an ominous wheeze of the blast, a hissing of a water-gauge – warning him respectively of a broken spring-hanger, a cutting valve, a slipped eccentric, a hot journal, the priming of

[9] I have tried to count them, and found only a few. The Wyandotte, Michigan company attempting to use Kelly’s patent and process employed a chemist briefly (Temin, p. 156). The Ironmaster’s Laboratory in Philadelphia offered chemical analysis by 1868. Pennsylvania Steel hired a chemist by 1868 (Misa, 1995, p. 34). A Connecticut crucible steelworks in 1868 seeked to hire “a qualified ‘scientific’ man to operate [the] steelworks.” (Gordon, p. 628) Carnegie’s firm hired a chemist by 1872.

> the boiler, high water, low water, or failing steam – these sensations, as it were, of his outer body, become so intermingled with the sensations of his inner body, that this wheeled and fire-feeding man feels rather than perceives the varying stresses upon his mighty organism (194).

Many of the developers of the various processes that together were able to produce steel discovered their part by intuitive methods. For instance, when David Thomas was working with George Crane in Yniscedwyn, Wales, to make a furnace that could run on anthracite, they were sitting and discussing a pamphlet by James Neilson, about the use of hot blast in furnaces. Williams relates:

> As Crane and Thomas watched the fire burning slowly and not too effectively in the grate, according to Thomas, the idea came to him that perhaps a hot blast applied to the fire would make the anthracite 'burn like pine.'"

This is a sensory understanding that leapt out of a deeply-rooted understanding of physical processes that did not rely on theory.

Holley's article however, does not say that the practical man's knowledge is sufficient to advance the industry. The article is a plea for the coming together of the college-educated chemists, just beginning to work in the industry, with the long-term ironworks and ironmasters who disdain them (as well as to add more practical experience to technological training). He called for "mutual respect and instruction" (200):

> When we see recent graduates patiently leading the untrained, confused, but determined mind of the workman, painfully wrestling with hard names and occult processes, into methodical habits of thought and the rudiments of organized knowledge; when we see the grimy workman, not standing aloof for fear of his craft or of his trades-master, but dragging the recent graduate into mines and furnaces, and patiently teaching him how to recognize that matter, in mass and under mighty forces, which he had heretofore contemplated in cabinet specimens, and chiefly in ideas . . . we may assure ourselves that one way has been discovered to promote the union of science and art" (p. 200).

The words that were analyzed above – experiment and test – are semiotic representations of this coming together of science and art (or, craft). "Experiment" was the word of the scientist – it was an official term, undertaken specifically to discover something about the laws of nature. "Test" was the word of the practical man, trying new combinations or processes to make steel. When the two came together for the purposes of producing a uniform and predictable product, "test" became the word for the practical assessment of the end-product of a product. "Testing" became embedded in the culture both as a practical method of answering a question and also as a way to establish standards. Both words, as well as how they appeared during this time period and came together, are examples of how the creation of a technology as complex as steel required the work of many hands, many minds, and many different ways of thinking.

Layers of Improving Technology

In the last 50 years we have seen a boom in information technology in which there were many improvements which have lowered prices and raised productivity in many sectors through many pathways. Several levels of technologies improved in parallel: semiconductor materials, chip design, computer design, operating systems, application software, network software, and Web browsers on top of all of the others. The dramatic effect of the information revolution comes partly from this compounding. There were positive (productivity-enhancing) feedbacks from the higher, dependent layers like software to the lower, more physical layers. In particular there were benefits from advanced chip design and simulation software to later generations of chips. The number of layers grew over time. For example, the application software layer barely existed in 1960 and the network, Web protocol, and e-commerce layers did not yet exist at all.

We see evidence that something analogous happened in the steel era. Articles in TAIME describe many apparent advances in mining and metal-processing technologies. In an article by Smock (1876), for example, new generations of compasses used to find magnetic iron ore were reported. Bayles (1884) expresses optimism about future uses of the microscope for chemical analysis of iron materials. There were improvements in blast furnaces, in Bessemer converters, in processing within plants to roll rails. Then the railroads improved because the rails improved. That is, a railroad required less maintenance if it had better rails. This did occur over time.

Production of information technology goods, recent decades

Higher, "downstream" levels

Business process (e-commerce, auctions, search engines)
Applications software (word processors, spreadsheets, databases)

Microcomputers
Semiconductor memory and microprocessor chips
Chip design and electrical engineering
Materials science and solid state physics

Lower, more basic, "upstream" levels

Iron and steel, 1871-1884

Higher, "downstream" levels

Business process (cost accounting)
Railroads and iron and steel plants
Bessemer and open hearth steel production
Blast furnaces making pig iron

Lower, more basic, "upstream" levels

The overall productivity effect was large. Fishlow (1966, esp. pp 630-645) evaluated the effect of various innovations on the productivity of railroads in the late 1800s and found that improvements in steel were more influential than any other identifiable innovation. Steel railroads survived ten times as much stress as iron ones and could support heavier trains which became standard over the period 1880-1910. Railroad productivity (measured by net revenues per hour or by revenues per unit costs of inputs) rose sharply during this period, which indirectly reduced the prices of any transported goods. These railroad fed back to cost reductions and technology improvements in steel making – they sped transit and lowered costs of moving coal, iron ore, rails, and other products all around. One core reason that the big steel producers centered themselves in Pittsburgh was that it was a rail center.

Furthermore, on top of the rails, so to speak, there were advances in business process which appeared upstream in manufacturing too. New accounting methods used by the railroads to manage their large operations were adopted by the iron and steel makers, whose plants became the largest establishments ever seen to that time in the U.S. Cost accounting was a central example (Meyer, 2005, pp 26-28; Chandler, 1977, p. 258-269; Clawson, p. 186; Nelson, p. 41). Other practices of large plants also diffused from the giant railroad companies to the iron and steel makers.

Conclusion

We see some evidence for the hypotheses that the new technology was associated with a rhetoric of uncertainty. We do not see evidence for the proposition that as the vocabulary of the field stabilizes, the articles become shorter. We observe an interesting phenomenon: that like the semiconductor revolution, many layers of technology were improving over time, with feedbacks to one another, and this is partly why the productivity increase was measured to be so great.

Bibliography

Bazerman, Charles. *Shaping Written Knowledge: the Genre and Activity of the Experimental Article in Science*. Madison: University of Wisconsin Press, 1988.

Bridge, James H. *The Carnegie Millions and The Men Who Made Them: Being the Inside History of the Carnegie Steel Company*. 1903. reprint by Kessinger Publishing.

Chandler, Jr. Alfred D. 1977. *The Visible Hand: The Managerial Revolution in American Business.* Harvard University Press.

Clawson, Dan. 1980. *Bureaucracy and the Labor Process: The Transformation of U.S. Industry, 1860-1920*. Monthly Review Press.

Fishlow, Albert. 1966. Productivity and technological change in the railroad sector, 1840-1910. In *Output, Employment, and Productivity in the United States after 1800*, vol. 30 of the Studies in Income and Wealth, pp. 583-646. National Bureau of Economic Research and Columbia University Press, New York.

Kuhn, Thomas. 1996. *The Structure of Scientific Revolutions*, third edition. University of Chicago Press.

Meyer, Peter B. 2003. Episodes of collective invention. US Bureau of Labor Statistics Working paper WP-368. http://www.bls.gov/ore/abstract/ec/ec030050.htm

Meyer, Peter B. 2005. "Turbulence, Inequality, and Cheap Steel" US Bureau of Labor Statistics Working paper WP-375. http://www.bls.gov/ore/abstract/ec/ec050010.htm

Nelson, Daniel. 1995. *Managers and Workers: Origins of the Twentieth-Century Factory System in the United States, 1880-1920*. University of Wisconsin Press.

Nuwer, Michael. "From Batch to Flow: Production Technology and Work-Force Skills in the Steel Industry, 1880-1920," *Technology and Culture*, 29 (1988): p. 808-838.

Smock, J.C. "The use of the magnetic needle in searching for magnetic iron ore", *Transactions*, Feb 1876, pp. 353-362.

Swank, James M. 1883. Statistics of the iron and steel production of the United States. In vol. 2 of the 1880 U.S. Census volumes.

Swank, James M. *History of the Manufacture of Iron in All Ages*. Philadelphia: American Iron and Steel Association, 1892.

Williams, Peter N. "David Thomas: Father of the American Anthracite Industry," *Historical Metallurgy*, 28(1), 1994.