Concept Formation and Subjective Knowledge: Analogy and Metaphor in the Early Days of Electrical Engineering

Fredrik Tell

Department of Management and Economics,
Linköping University,
SE-581 83 Linköping
Sweden
Tel: +46 13 282599
E-mail: frete@eki.liu.se

Paper to be presented at the 6th European Conference on Organizational Knowledge, Learning and Capabilities, 18-19 March, Boston: MA, USA

Abstract

This paper discusses a particular type of knowledge, subjective knowledge, and its implication for inventive and entrepreneurial activity. The justification processes of subjective knowledge primarily involve internal coherence and procedural reasoning. These characteristics make subjective knowledge an interesting candidate for the analysis of concept formation in contexts where fundamental uncertainty is prevailing. Drawing upon theories of analogical reasoning in knowledge generation, processes and mechanisms of concept formation is discussed in the paper. Moreover, it is argued that such processes bear strong resemblance to the justification of subjective knowledge. The idea of concept formation through analogical reasoning is illustrated by a case study of two of the foremost inventors/entrepreneurs in the genesis of the electrical engineering industry: Thomas Alva Edison and George Westinghouse. While Edison used ideas as “subdivision of light” and gas lighting systems as base domains for analogy, Westinghouse’s inspiration came ideas such as “central station” and used gas distribution and rail signalling systems as his primary bases for analogy. Both of them early on also recognised the importance of imagination in conceptualizing the future uses of their system in realizing concepts into viable products. Some implications for theories of organizational knowledge are suggested.

Keywords: Knowledge generation, analogical reasoning, concepts, subjective knowledge, innovation, electrical engineering

Suggested track: B. Knowledge creation and innovation, e.g., in R & D

Concept Formation and Subjective Knowledge: Analogy and Metaphor in the Early Days of Electrical Engineering

1. Introduction

Studying competition, technical change and economic growth in the infancy of the electrical manufacturing industry, Harold Passer remarked: “A key person in this process is the engineer-entrepreneur, the person with technical training who can see commercial possibilities in the application of scientific principles and who labors to perfect usable products and techniques” (Passer, 1953: 1). Historian of technology Thomas Hughes further elaborates as he discusses the role of independent inventors in *American Genesis*:

> […] they performed the entrepreneurial function of establishing companies because they wanted to bring their inventions into use. They had to establish companies because they found that firms busily presiding over well-established technologies were usually not interested in nurturing radically new technologies with which their employees had no experience and for the manufacture of which their machines and processes were not suited. (Hughes, 1989: 24)

The foremost of such engineers are those coined “system builders” by Hughes, developing massive and complex systems for producing and using, for instance, electricity, telecommunication and automobiles (Hughes, 1989: 3). As pointed out by Hughes, these system builders, like Henry Ford, believed in the rational organisation of a future society, which would serve the ends of mankind. This depiction of entrepreneurial activity departs from discussions about organisational routines and communities of practice commonplace in contemporary writing about organisations, innovation and knowledge in several respects. In this essay, I will try to disentangle a model for enhancing our understanding of more deliberate behaviour in entrepreneurial activity, showing how the formation of concepts relates to the underlying knowledge base of organisations and their members. The purpose of this discussion is to provide an interpretation of entrepreneurial activity as “mindful”, albeit based in an unconscious (or tacit) understanding of engineering, business and societal needs. The point of articulation of ideas into concepts, however, is the enhanced ability to model possible futures: to, as it were, probe deeper into the uncertainty and ambiguity of times to come.

People involved in these activities struggle with the uncertainty of the future and try to impose a “new reality” on the future. They are not passively accommodating to future events but try to enact the proceedings of human life (some successfully, some less so). The central question discussed in this paper is: how do they go about doing so?

Deeply intertwined in the process of invention is its realisation through innovation. Innovation requires organisation (in particular when it comes to large technical systems as discussed in this paper). The understanding of technological innovation as a social process brings certain implications. As social and organisational factors influence the innovation process, any inventor/entrepreneur also take into account the organisation of e.g. production and marketing. To convey the meaning of technological invention, the inventor/entrepreneur articulates his/her ideas. However, invention also implies a conception of something not yet realised in the external world. Given the complexities of systems involved such articulation and representation may aid in untangling system inter-relatedness. Certain visions of a future social structure (e.g. society) may be implied by the conception of the invention, explicitly or implicitly. In this process, language becomes an important instrument, whereby both social and cognitive processes are used in “foreseeing”. Different knowledge bases are utilised by the inventor and contribute to the formation of concepts. In sum, if concepts are more than representations of existing features of the world – instead used by inventors to envisage future states of the world – how can we describe the process of concept formation that seem to take place?

Innovation and knowledge creation have formed central foci in recent theorising on the functioning of organisations (see e.g. Nonaka and Takeuchi, 1995; Weick, 1995; Baumard, 1999). On a micro-level, Nonaka and Takeuchi (1995) in particular, emphasise the use of metaphors and analogies in knowledge creation processes (in the process they denote externalisation). In this paper we will further elaborate on the use of metaphors in the context of “envisaging futures”. In contrast to more “realist” accounts of organisations as passively reacting to external environments (Daft and Weick, 1984; Tsoukas, 1996), we here identify the process of concept formation and elaboration as central in the innovation process. We connect this process to the different types of knowledge generated and used in organisations and show how the internal but intentional justification of subjective knowledge allows for representation of possible futures “sheltered” from an “external” reality, but sufficiently “rational” to allow for conscious enactment. Examples from the early stages of the electrical engineering industry are used to illuminate these ideas.

The paper is structured accordingly. Starting from a pluralistic model of organisational knowledge, next section elaborates on subjective knowledge and justification by coherence and procedure. The third section introduces a notion of analogical reasoning consistent with subjective knowledge. The fourth section describes early inventors in electrical engineering and their use of analogical reasoning and vision in trying to foresee future states of the world. The fifth section discusses some general ideas on the role of concept formation in engineering practice. The sixth section offers a discussion and concluding remarks.

2. Subjective knowledge: Justification, coherence and procedure

Nelson and Winter (1982) argued that organisational knowledge primarily involves routines, that is to say the knowledge of how to do things (knowing how rather than knowing that [Ryle 1949]). Such practical knowledge is often conjectural and fallible, giving rise to an anticipatory interpretative framework (Polanyi 1962: 103). Agents encounter the world embracing a number of hypotheses on how it works. Loasby (1993: 205) states "[…] people try to make sense of their world by imposing their own interpretative framework on it, and use this framework to guide their actions." In turn, conjectural knowledge may with more or less difficulty, be changed when learning and new knowledge development occurs. In particular, hypotheses and interpretative frameworks of organisational members carry a certain dispositional element, i.e. they are property attributing or ascribing a propensity of what a certain agent is able to do (sometimes in a specific context). This is however not the same as saying that this property of an agent is governed by a deterministic law. As put by Ryle (1949: 114):

> Dispositional words like 'know', 'believe', 'aspire', 'clever', and 'humorous' are determinable dispositional words. They signify abilities, tendencies, or proneness to do, not things of one unique kind, but things of lots of different kinds.

The dispositions towards the world may or may not be of an explicit kind. If such knowledge is implicit it resembles what Polanyi (1983) calls tacit knowledge, subsumed during the performance an activity. As argued by Reber (1993), this knowledge is often carried implicitly by someone who is learning, but learning does not only occur within the realms of these implicit assumptions. Implicit learning (i.e. upgrading of implicitly carried paradigms), however, may also take place (cf. Loasby 1993). Dispositional knowledge can be explicitly expressed e.g. in beliefs. An important feature of knowledge is belief and concept formation. In developing knowledge, e.g. in science, conceptualisation and formalisation is an important element whereby agents develop their cognitive frameworks by revealing logical structures between certain elements of the world. This leads to yet another feature of knowledge, some practical knowledge (although, of course not all) can be put into code, i.e. codification can take place (Boisot, 1995; Cowan and Foray, 1997; Prencipe and Tell, 2001).

However, one problem arises when trying to understand codification, conceptualisation and articulation as an inventive process. Despite being ‘manageable’ by humans, how do the symbols refer to the ‘real’ or ‘external’ world in which an invention is supposed to work? In trying to reveal the process of concept formation and knowledge creation, I will here make use of a pluralistic model of organisational knowledge and justification (figure 1). The chief aim will be to show how concept formation can be understood as an articulation in a form of subjective knowledge – making use of analogical reasoning, but being justified through internal coherence rather than against an external foundation.

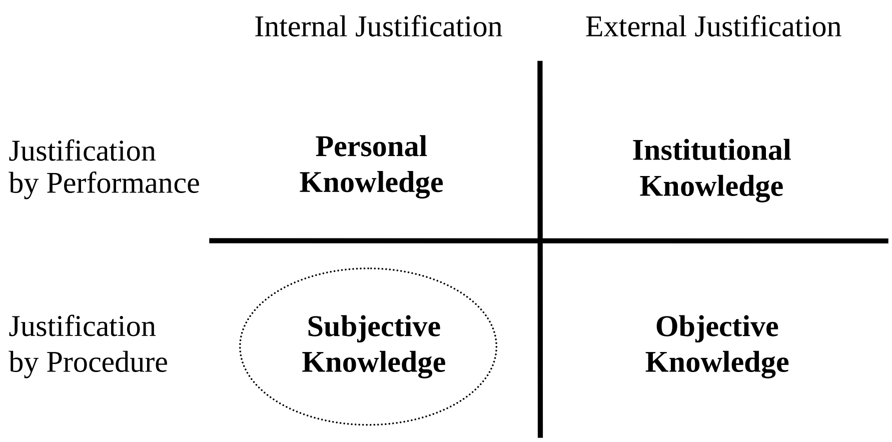

Figure 1. Four types of knowledge and contexts of justification: subjective knowledge as justified internally and by procedure (adapted from Tell, 2004)

Central to this understanding of subjective knowledge is the concept of coherence. Coherence serves as a fundamental means of internal justification of subjective knowledge (Tell, 1997; 2004). Justification of subjective knowledge is an inherently systemic activity where the crucial criterion is a belief’s coherence with the body of beliefs already carried.

> …the [coherence theory of empirical knowledge] holds that the justification of particular empirical beliefs is always inferential in character, and that there can in

> principle be no basic (or initially credible) empirical beliefs and no foundation for empirical knowledge. (Bonjour, 1986, p. 120)

The knowing subject is seen as having a system of beliefs, including ontological and epistemological assumptions. Justification is given with regard to this system, reasons cannot be found outside it. Within a system of beliefs one is justified in believing anything that will facilitate an explanation in accordance with the system of beliefs upheld (Lehrer, 1974). An internal justification for a knowledge claim is thus, contrary to the external justification salient for objective knowledge, *dependent* upon other beliefs held by the knowledge claimant. This position is readily reconciled with a self-referential understanding of organizations. A social system may refer to itself by its ability to make "distinctions" (von Krogh and Roos, 1995; Luhmann, 1995: Tsoukas and Vladimirou, 2001). The very idea of organizations and their members as enacting their environments (Daft and Weick, 1984), supports the notion of knowledge justification as a process where a coherent "fit" with internally upheld assumptions is the outcome. Standards, roles, and rules from this perspective become self-selected or self-imposed (March, 1994).

Another important facet in the justification of subjective knowledge is the reliance on procedural reasoning. This means that cognizing agents are supposed to act under some norms of rationality and consciousness. While objective knowledge as discussed e.g., in philosophy of science, has leaned on rationalistic assumptions (Newton-Smith, 1981), the *procedure* in which the argument is presented, how data and warrants are used is equally fundamental for understanding the notion of subjective knowledge (Toulmin, 1958). Showing the logic of how hypotheses have been deduced, and the way these hypotheses have been confronted with empirical facts, gives the argument and justification for the knowledge claim. Following the procedure "certifies" the knowledge claim, making it universally understood, reproducible and possible to evaluate. *Inference* guides the procedure of rational justification, and an outcome of this process is theories, models and other abstractions. In organization studies, March and Olsen (1989) call this rationality the "logic of consequence". Action founded on such premises may rightfully be conceived as rational action from a decision-making perspective (Brunsson, 1982). There is a *reason* for acting in accordance with the decision made, if the right methods for gathering and evaluating information have been used.

3.”Analogically speaking”: On coherent concept articulation

Apart from philosophy of knowledge and truth, the idea of coherence has been used in a number of academic disciplines. In *physics*, it is particularly associated with descriptions of waves (e.g., light, acoustic, hydrodynamic, and electromagnetic waves). Wave movements with the same frequency and with constant relative phases are considered coherent. A common expression for this type of coherence is “being in phase” with each other. In *linguistics*, coherence denotes a set of relationships within a text that link sentences by meaning. Coherence often depends on shared knowledge, implication, or inference. Coherence is also used semi-technically of the way in which the content of connected speech or text hangs together, or is interpreted as hanging together, as distinct from that of random assemblages of sentences. In *informatics*, coherence is used to describe the constancy of a property over an area. Computer-graphics algorithms often take advantage of area coherence, image compression being an example. In *psychiatry*, the term “central coherence” is used when diagnosing autism. This concept refers to the ability of putting our fragmented impressions into a coherent whole. Our normal behaviour is to collect information into coherent wholes e.g., many people in line constitute a queue; many trees become a wood, etc. This is called central coherence, and it can vary among people. People with autism lack, or have very weak, central coherence. This implies them only seeing parts without any internal connections, which makes the world to appear fragmented and difficult to understand. In one theory of the firm suggested in *economics*, corporate coherence refers to the relatedness of a diversified firm’s constituent businesses (Teece et al, 1994). Such coherence distinguishes the viable firm as a historical entity, rather than just an arbitrary collection of businesses (Foss et al, 1995).

Common to these definitions (perhaps with the exception of physics) is a notion of coherence that is used for ascribing relational structures (often in a quite holistic fashion). In addition, the notion of coherence as used in physics reveals another aspect of coherence, namely its analogical connotations. As has been discussed by Nonaka and associates (Nonaka, 1994; Nonaka and Takeuchi, 1995; Nonaka and Konno, 1998), the use of analogy and metaphor are important tools in knowledge generation. In particular, Nonaka’s analyses points to the importance of analogy and metaphor in “externalisation” processes, that is, in the explication of tacit knowledge (cf. Nonaka and Takeuchi, 1995: 64-65). Such an understanding, albeit somewhat unspecified, ties in to the understanding of subjective knowledge as suggested in this paper. But how does analogy and metaphor work? Inspired by Tsoukas (1993), I suggest that in the justification processes involved in subjective knowledge, analogical reasoning plays an important role. Referring to the work of Gentner (e.g. 1983; 2002), analogical reasoning can be understood as structure-mapping from a base domain to a target domain. This line of work suggests that metaphors are very much like analogies (Gentner et al, 2001).

According to the structure-mapping theory of analogical reasoning (Gentner, 1983), the rules for mapping knowledge through analogy depend on syntactic properties of representations, rather than specific content properties. This means that the mapping of one representation (base) as something else (target) in an analogy e.g., “an organisation is like a machine” refers primarily to the logical or causal relationships involved in the concept of a machine (and not the object-attributes of a machine). Using the distinction between attributes and relations of a representation, it is possible to derive a scheme for various types of domain comparisons (table 1).

	Attributes	Relations	Example
Literal similarity	Many	Many	Milk is like water
Analogy	Few	Many	Heat is like water
Abstraction	Few[1]	Many	Heat flow is a through-variable
Anomaly	Few	Few	Coffee is like the solar system
Mere appearance	Many	Few	The glass table-top gleamed like water

Table 1. Kinds of domain comparisons (Gentner, 1983: 161; 1989: 206)

Table 1 refers to the first mapping principle suggested by this theory, namely by the mapping of relations (and not attributes) from base to target. The second important mapping principle deals with the determination of particular relationships. In this respect, the structure-mapping theory suggests that particular relationships are determined by the existence of higher-order relations, which define *systematicity*.

> Systematicity suggests that, all else being equal, matches preserving connected systems of relations are preferred to matches preserving isolated matches. This assumption of systematicity is rooted in an assumption that connected systems of

[1] Abstraction differs from analogy and other comparisons in having few object-attributes in the base domain as well as few object attributes in the target domain.

> relations are often the elements that provide a deep *coherent* interpretation of an analogy (Markman, 1997: 375, emphasis added).

The idea of systematicity has strong implications for the justification of subjective knowledge as discussed in section 2. First, systematicity refers to a principle of coherence (Gentner and Bowdle, 1994), suggesting that coherence (in terms of mutually interconnected principles) determines which concept in the base domain that is more likely to be imported into a target domain (cf. Gentner 2002: 28). Moreover, the hierarchical structure of higher-order predicate structure in the systematicity definition suggests a procedure for reasoning (cf. Gentner, 1983: 162-163). Since both principles for justification of subjective knowledge are supported, the structure mapping theory of analogical reasoning serves as a good candidate for examining subjective knowledge generation.

Gentner (2002) explore how analogical reasoning can lead to conceptual change. She uses the scientific work of Johannes Kepler as a case study. Her study shows how Kepler's analogy using light as a base domain, led him towards a cosmological theory where the sun was the force/power (*vis motrix*) in determining the speed and orbits of the planets. This involved some major conceptual change (table 2).

Before	*After*
Planetary system is governed by mathematical laws	Planetary system is governed by physical causality
Planets orbits are crystalline spheres containing planets or eternal circles travelled by planetary intelligences	Planets' orbits are paths continually negotiated between the Sun and the planets
Celestial phenomena are separate from earthly physics	Terrestrial knowledge extends to astronomical phenomena
Planetary paths are perfect circles of uniform speed	Planetary paths are ellipses, faster when closer to the Sun and slower when further from the Sun.
Anima motrix as "spirit" in Sun that moves planets	*Vis motrix* as "force" from Sun that moves planets

Table 2. Conceptual change involved in Kepler's new theory (Gentner, 2002: 27)

In developing his theory, Kepler used three principal analogies. The first was viewing the sun's power as analogous to light. The second was the idea that the sun's power could be likened to magnetism. The third analogy was that the sun's power could be viewed as a current in which the planets navigated as boatmen (Gentner, 2002: 31). In similarity to e.g., Hughes (1983), who stressed the importance of so called "reverse salients" as focusing devices in technological progress, Gentner (2002) suggests that inconsistencies acts as principal *motivators* for conceptual change. Analogy, however, she proposes, acts as the *process* whereby conceptual change takes place. In particular, she stresses that creativity should be understood not as conceptual fluidity, but that "a better model of the creative process begins with a representational structure and alters the structure, sometimes locally and sometimes radically" (Gentner, 2002: 36). In the next section, we will look at the creative spirits involved in shaping the electrical engineering industry.

4. Early invention in electrical engineering: visions, concepts and analogy

During the late 19th century an era of technological innovation sometimes denoted the "second industrial revolution" took place. Among the most conspicuous technologies to experience radical development during this era was electrical engineering. Viewing engineering as knowledge, Vincenti (1990) suggests that design encapsulates the distinguishing facets of engineering knowledge (from scientific). In particular, Vincenti stresses the organising features of the design process.

> A key term […] is the word *organizing*, for which we could also read *devising* or *planning*. This word selects engineering out from the more general activity of "technology," which embraces *all* aspects of design, production and operation of an artifice. (Vincenti, 1990: 14, emphasis in original)

Using the terminology of Vincenti, the inventors of early electrical engineering partook in a process of *radical* design, in contrast to *normal* design (the latter which is probably more common in engineering). That is, the engineers did *not* know at the outset of development work how the device in question would operate, neither its customary features. Thus, inventors in electrical in this period had to organise and plan under circumstances of great uncertainty. One could actually argue that they were devising possible futures. How did the use foresight in this process?

Some of the world's most famous inventors took part in the development of electrical engineering. These were exciting times. Most famous of them all was the "Wizard of Menlo Park": Thomas Alva Edison. Hughes (1979: 124), quoting Isaiah Berlin, describes Edison as a hedgehog, someone "who relate everything to a single central vision, one system less or more coherent or articulate." Being a system-builder, he was an archetypal inventor-entrepreneur (as different from e.g. manager-entrepreneurs and financiers-entrepreneurs). His inventive style, writes Usselman (1992: 257-258), was one where he and his associates utilised an evolving standardised repertoire of approaches that could be brought to any problem. In particular, Edison's inventive capacity had novelty as a top priority. In developing a electrical direct current (DC) system for incandescent lighting between 1878-1882, Edison targeted primarily businesses like hotels, restaurants and shopping districts (Passer 1953: 114). Incandescent lighting was a cumbersome invention, to which Edison drew the analogy with a complex machine.

> For Edison, the search for a practical incandescent light was a bold, even foolhardy, plunge into the unknown, guided at first more by overconfidence an a few half-baked ideas than by science or system. (Friedel et al, 1986: xii)

One of the formidable strengths of Edison, however, was his ability to ask pertinent questions (Hughes, 1983: 26). Working with his staff at Menlo Park, people like Francis Upton, Francis Jehl and Charles Batchelor, he relied on their theoretical insights in responding to the questions he set about the new devises he explored would function. Francis Jehl, who had arrived at the Menlo Park laboratory in 1879, credited Edison's success in developing incandescent lighting to "his early vision, far in advance of realization" (Hughes, 1983: 33). According to him, Edison had commenced systematic work upon the incandescent lighting system over 12 months before a practical devise was designed. Moreover, he coined the expression: "invention is 1% inspiration and 99% perspiration". New ideas were combined with refinements of old and new combinations.

> Edison seems to have been refining his inventive ideas for components and his more general ideas for a system throughout the fall of 1878 […]. His early emphasis on the durable filament and parallel wiring was specific, but his notion of a system involving generators, lamps, and distribution from a central station was vague. He probably first conceived it as an analogue of central-station, illuminating gas supply. (Hughes, 1983: 34)

What was then the vision driving Edison towards the realisation of a functioning incandescent lighting system? The conceptualisation of the new invention Edison was working with he denoted "subdivision of light" (Friedel et al, 1986: 23). Returning from a trip with Professor George Baker of University of Pennsylvania, to recover from a period of tiredness, in late August 1878, Edison commenced work upon incandescent lighting within two weeks. What was the impetus? In September, Edison visited the factory of Wallace & Sons. The dynamo developed by Wallace fed eight electric lights at one time; this was the system Edison wanted to emulate on a grander scale. He was to devise a distributed lighting system reaching into every house. The gas-system provided an obvious model for any electric lighting system (Friedel et al, 1986: 64).

> From the beginning of his work on the electric light, Edison made no secret of his conception of a system patterned after gaslight. […] gas represented more in Edison's mind than the competition – it was the guiding analogy every step in the way. The entire concept of "subdivision" of current was to a degree a product of the gas analogy, and certainly the insistence on independently controlled lights, necessitating parallel distribution circuits and high-resistance lamps, was directly modelled on the key feature of gaslighting. The model went beyond even these considerations, however, and determined other elements that in retrospect were unnecessary. The best example of this excess influence of gas is in the pursuit of underground distribution. (Friedel et al, 1986: 177-178)

In order to provide incandescent lighting, Edison foresaw how a spiral-formed filament could be heated to incandescence (albeit many inventors previously had worked on the idea of incandescence). He set out to write a document that outlined the design of such an incandescent lighting system, and deemed the major problem to be how to disallow the filament to reach its melting point. Therefore, in this document he described 44 different regulation devises for temperature regulation (Friedel et al, 1986: 9-13). He was sufficiently confident that his new designed would rapidly solve all problems that had eluded previous inventors that he boasted in the *New York Sun*, 16 September 1878:

> With the process I have just discovered I can produce a thousand – aye, ten thousand [lights]– from one machine. Indeed, the number may be said to be infinite. When brilliancy and cheapness of the lights are made known to the public – which will be in a few weeks, or just as soon as I can thoroughly perfect the process – illumination by carbonated hydrogen gas will be eliminated. (Friedel et al, 1986: 13)

He then went on to describe how he could light all of lower Manhattan with a 500 horsepower engine, through a system of underground wires that would bring electricity into buildings. Several newspapers reported the story and Edison's representative and friend Grosvenor P. Lowrey requested a business meeting with Edison and various financiers on how to capitalise on the invention. Everything based on the single document produced so far by Edison in his investigations in incandescent lighting!

On October 15, 1878, the *Edison Electric Light Company* was incorporated. Edison got help from Grosvenor P. Lowrey who assembled a dozen men to come up with the capital stock of $300,000 (Passer, 1953: 84-85). At this stage, one could say, Edison formally turned from an inventor to an innovator. Although his inventions already earlier had commercial purposes, he was now able to commercialise new inventions himself through this company. The J. Pierpoint Morgan banking group supported the company and its activities. This was particularly important since the lighting companies that were to utilize Edison's power systems had to be established and this needed financing, this now could be provided through the banking connections. For the installation of the Pearl Street Station system, he founded the *Edison Illuminating Company of New York*. Edison also needed funding for the heavy investments in R&D required for inventing a complete system for incandescent lighting. More stock was issued and Passer (1953: 88) estimates the cost of putting the incandescent lighting system into a commercial stage to be nearly half a million dollar.

As Hughes (1983: 36) shows, the logical deduction from Ohm's law, increasing the resistance of the filament in order to reduce current in relation to voltage and thus lower conductor losses, was the crucial innovation in the development of the incandescent lighting system. Then came the long and tedious search for a proper filament material (which ended up with wolfram). At about the same time (late 1879) as a workable filament was found, a new generator design emerged and the Edison team could start focusing on the design of the system and its components. Following the success of this development one can view Edison as the innovator of power distribution systems, in particular after the inauguration of the Pearl Street Power Station in New York City 1882.

Some of the problems encountered by Edison and his associates at Menlo Park referred to which material to use for filaments. They tested a number of materials: e.g. platinum, iridium, platinum-iridium, carbon, chromium, aluminium, silicon, tungsten, molybdenum, palladium, and boron. But there were few visible and positive results. Friedel *et al* (1986: 31) also contend that Edison was working at the whole system at this time. Rather, the focus was placed of the self-regulation of heat as the key to successful light: "other aspects were simply not seen as important". Thus it seems that Edison did not old a very sophisticated view on the system requirements at the time (1878), but that this allowed for decomposition and analysis of a crucial sub-component. However, towards the end of 1878, all work on filaments had ceased in favour of the new design of the generator for the system (Friedel et al, 1986: 43; 69). It was recognised that the Wallace generator (dynamo) design was insufficient for a large system of incandescent lamps and in April 1879, the engineers at Menlo Park came up with a new and improved design. The solution of that problem meant that they could return to the filament issue, and Edison himself realised that carbon was the best filament found so far. However, it could not easily be formed into a spiral, but a horseshoe-shaped filament made from carbonised cardboard became the working prototype (Friedel et al, 1986: 105). After further experimentation, the first incandescent lamps from Edison had filaments made of bamboo. Manufacturing could begin.

Edison's lamp production was performed in the Menlo Park, Newark, laboratory until the end of 1880. Then Edison and some of his associates formed the *Edison Lamp Company*. This partnership reached an agreement with the *Edison Electric Light Company* in spring 1881. At first the production continued in Menlo Park but was in 1882 moved to Harrison where labour supply was superior. About the same time Edison was also a partner in a newly established firm, *Bergmann and Company*, formed to supply components and accessories to the Edison system. For the manufacturing of dynamos, Edison established the *Edison Machine Works* in 1881. Further, to manufacture underground conductors, Edison founded the *Electrical Tube Company* the same year. Most of these companies were located in New York City, therefore it was natural for Edison to move the rest of his operations there.

Edison's contemporary and great adversary, George Westinghouse, founded his first company in 1867, at the age of 21, to market a railway device he had invented. This company was dissolved the year after but in 1869 when he invented the air-brake, the *Westinghouse Air Brake Company* was organized. During the upcoming decade, he spent much time in Great Britain marketing these brakes. There he found out about switching and signalling devices, and decided to enter that business. In 1881, he bought one company in Pennsylvania and one in Massachusetts, which he combined to form the *Union Switch and Signal Company*.

> Within a few years, Westinghouse invented a number of automatic switching and signaling devices for his new firm. In these inventions, he combined a force familiar to him, compressed air, with a force new to him, electricity. (Passer 1953: 130)

He also found out how to utilize natural gas and in 1883 formed the *Philadelphia Company* for the distribution of gas to factories and residences in the Pittsburgh area. In these operations, the company developed capabilities in long-distance systems for conveying gas. Ingeniously, Westinghouse saw the potential analogy with electrical power distribution.

> The high pressure at the well could force large quantities of gas through small and inexpensive pipes for distances up to four and five miles. But such a high pressure could not be utilized by the gas consumer. To reduce the pressure to the level

> which was safe for ordinary use, Westinghouse widened the pipes near the place of gas consumption. The concept of a gas-distribution system which uses high pressure for transmission and has a device to convert this high pressure into usable low pressure for consumption is analogous to the concept of an electrical distribution system which uses high voltage for transmission and has a device to convert this high voltage into usable low voltage for consumption. The pressure-reducing device for the gas system was the large-diameter pipe. The pressure-reducing device in the electrical system was to be the transformer. The success of Westinghouse in developing a high-pressure system of gas distribution gave him the confidence in his ability to achieve similar success in developing the alternating-current system of electrical distribution. (Passer 1953: 131)

Already in 1883 Westinghouse had commenced studying, and hiring people to work with, direct current (DC) systems that was Edison's forte, "[…] but not until had his vision of the possibilities of the alternating current [AC] was his interest thoroughly aroused" (Prout, 1921: 91). In 1885, Westinghouse read in an English engineering periodical about an AC system for electrical transmission using the transformers developed by Lucien Gaulard and John Gibbs. Westinghouse realised how the use of AC technology could provide with an economical system for electricity distribution by the 'stepping up' and 'stepping down' of voltages. Facing great opposition within his company organization, George Westinghouse pursued the development of an AC-based system for electricity distribution, despite the fact that he was not very knowledgeable yet in the field of electrical engineering (Passer, 1953: 132). The development work however, was so promising that the electrical department of the *Union Switch and Signal Company* was incorporated as a separate company, the *Westinghouse Electric Company*, that was formed on January 9, 1886 with a capital stock of $1 million (Passer, 1953: 136). As pointed out by Usselman (1992), Westinghouse differed quite dramatically in his approach to innovation from Edison. Whereas, Edison invented for public showcases, Westinghouse was more interested in industrial applications and the interest of industrialists. Moreover he organised innovation and production concomitantly, in a manner that would be quite the norm in electrical equipment manufacturing for years to come (cf. Chandler, 1977; Wise, 1985, Usselman, 1992).

> In the field of electricity he was not an inventor of fundamentals. He invented many useful things, but his great work was in stimulating, combining, and directing the work of other men. (Prout, 1921: 90)

The central thought that was occupying Westinghouse's mind when he was to build his electrical companies on a foundation of what Prout (1921: 117) calls the central power-station idea (cf. the similar attitude of Westinghouse's and Edison's contemporary Elihu Thomson [Carlson, 1991]). The central power-station idea was grounded in the manufacture of electrical power in large quantities, at advantageous locations, and then to distribute it for use.[2]

> It is not possible to say when the thought of central power systems first took place in the mind of Westinghouse. He did, however, develop the idea of converting energy into useful power on a large scale at suitable places, carrying it greater or less distances, and distributing it for the "use of the convenience of man". (Prout, 1921: 118)

One salient feature of many of Westinghouse inventions, thus (e.g. electrical power transmission, the railroad air brake and the interlocking signalling system) was that they involved transmission over distance. Another feature that recur is the use of linking technologies that connected or regulated systems. Examples of such are the electrical transformer and the rotary converter (Usselman, 1992: 271-272). In his inventions, just as Edison, Westinghouse exhibited an understanding of new devices as systems, often interconnected with other systems in time and space. He recognised that uniformity and standardisation was important issues in network industries as railroad and electricity (Usselman, 1992: 286).

> For years he thought of compressed air along the lines of railroads to handle, not switches and signals alone, but cranes, capstans, riveters, hammers and other tools. It was an alluring notion which was in his mind long before he begun to think of the uses of alternating current, and lingered there long after the epoch-making developments in electric transmission at Niagara Falls. (Prout, 1921: 119)

Moreover, Westinghouse did rapidly concentrate on few technologies, key applications and manufacturing problems, in contrast to the frisky elaborations made by Edison. In the words of Vincenti (1990), his was a more normal design than Edison's. The vision of Westinghouse was thus more focused and more pragmatic than his contemporary competitor. One source for this view was his background in the railroad industry, an industry that with the emergence of electrical traction developed into an important customer for Westinghouse's electrical ventures. However, his use of models and

---

[2] Instead of letting power be generated in smaller quantities where it was used (cf. water-wheels or steam engines).

analogies in the design process very similar, both of the inventors stemming from the same machine shop culture (Usselman 1992: 278; 299).

5. Models, metaphors and vision in concept formation

The examples provided above reveals some interesting insights to the times and lives of some of our great inventors: Thomas Edison and George Westinghouse. However, of particular interest here is the way they conceptualised their inventions and future usage. It is in this context concept formation plays an important role in creating new knowledge. As put by Hughes (1989: 77): “To invent machines, devices, and processes by metaphorical thinking is similar to the process of word creation.” To say that such processes constitute an important part in foresight is to recognise that such foresight is indeed fallible. Neither Edison nor Westinghouse, confident as they were, had little claim to say that the “knew with certainty” what their inventions would imply. However, new conceptualisations as e.g. subdivision of light or electricity as compressed air or gas provided them with visions of a possible future system that would have great implications for social and economic life. One can, as Hughes (1989) suggests, view the word/metaphor used in its new sense as the principal subject, while the word with which it is compared (used in its literal/conventional sense) is the subsidiary subject.

> Metaphor provides for the inventor a bridge from the discovered or invented into the realm of the undiscovered. […] The inventor must use the future tense when referring to the primary subject, for it has yet to be invented. (Hughes, 1989: 77)

In the brief narrative provided above, we have primarily focused on the grand visions held by Edison and Westinghouse and how they related to the innovative process. However, as is further elaborated by Hughes (1989: 78), inventors often conceptualise metaphorically on a lower level too, in creating visual drawings, scale-models or representing words. In this process, as well as in the process of creating a higher-order vision, models of the world function as a device for projecting attributes into an unknown future. According to Morgan (1999: 353), who studied the use of models in economic science, models are more than illustrations. One cannot merely look at a model and then move on – the model is put into work and a reader/user must follow the model in order to understand what is going on. Applied to a model as metaphor, this suggests that the implications of using the metaphor as referring to the primary subject must be drawn out, which requires substantial cognitive effort. In order to learn from models, Morgan (1999) suggests that that we learn in two ways from models. Firstly, we learn by designing the model. Here, in this case, the inventor learns what will fit together and how the model can be used to represent the primary subject. During this process a number of design choices needs to be made, in order to create a model that provides a consistent and coherent framework for envisaging the problem at hand. By making such choices, the designer of the model will undergo a learning process. Secondly, we learn by using the model. We transfer what we learnt from our manipulation of the model to a theory (for instance by further abstraction into algebra) or the real world (for instance by the development of a concrete device or action). This means that further re-arrangement of the model may take place or that failure of the model to represent the primary subject (world or theory) will be recognised (cf. Foray and Steinmueller, 2001). Also in these situations models as metaphors provide vast opportunities for learning.

6. Discussion and conclusions

So in what way does concept formation and knowledge relate to each other, and what implications are there for organisational foresight? In this section I will just provide some tentative remarks on the nature and dynamics of concepts as a form of subjective knowledge.

The first point is that the character of concepts as they are formed through analogies, metaphors or other model-building suggests that they to some extent are subjective in the sense outlined above. They are subjectively rational in the sense that the inventor forming the concept finds them coherent with previously held assumptions or notions. Hence, there is room for argument about the content and implications of the concepts developed. Moreover, they are concepts subjectively held, justified within a specific realm of the inventors knowledge and practice. As discussed by Hughes (1989: 25; 27), inventors needed “sheltering” from the outside world where hostility and ridicule could undermine the confidence of the inventor. Drawings and models could easily be “suffocated” in such contexts.

Secondly, concept formation can be seen as a process of articulation (Prencipe and Tell, 2001; Zollo and Winter 2002), providing increased deliberation in organisational learning processes. While the behavioural focus on learning as routine-based, neglects some of the deliberative processes involved in organisational learning (Nonaka and Takeuchi, 1995; Witt, 1998; Zollo and Winter, 2002), there are arguably elements of substantive rationality or logic of consequence involved (March and Olsen, 1989).

Through agents' abilities to express opinions and beliefs (Zollo and Winter, 2002), the ability to develop visions (Fransman, 1994) and the creation of metaphors and analogies (Nonaka and Takeuchi (1995), cognitive processes drawing more global inferences and determining causalities are triggered.

Thirdly, it is important to enunciate the sources of concepts. Where do they come from? In the framework provided here, concepts can be generated from internal "subjective" dynamics as well as by drawing upon other contexts of justification. Starting with the latter, the Westinghouse story discussed in this paper indicated that he was able to draw upon the "family resemblance" (Wittgenstein, 1953) provided by the institutional knowledge of e.g. the railroad industry. By comparing institutional settings, distinctions can be drawn, and concepts articulated. Moreover, despite the claim that the development of electrical engineering was quite distanced from the scientific community (emphasised many times by Edison), the use of objective – scientific – knowledge as e.g. Ohm's law or Maxwell's equations provided impetus for several Eureka moments where conceptions were formed. Based in several interpretations of the primacy of tacit knowledge (see e.g. Polanyi, 1962; Penrose, 1989; Reber, 1993 for quite different variants of this argument), one can on the one hand argue that articulation of concepts stems from what first is personally understood tacitly, and on the other hand also argue that there are limits to what can be conceptualised.

Fourthly, and given that concept formation is possible and an important feature in learning processes and the ability to create organisational foresight, there are certain "internal" dynamics of subjective knowledge that makes it a viable candidate for further exploration. The emphasis on internal but still procedural justification allows for "off-line learning". As pointed out by Morgan (1999), the design of models provides rich learning opportunities. Given that learning is a trial and error process, there are here opportunities for trials with limited consequences. Various representations of current and future states of the world can be simulated and this, in turn allows for different "probes" into the unknown. Representation needs not to be exact as in a scientific theory or artefact, but it is sufficient that certain analogies and implications can be derived. Moreover, an important feature of concepts as a form of subjective knowledge is that they can be stated as atoms or modules despite a highly systemic context. For example, as Edison was developing his incandescent lighting system, there were a number of interactions and sub-systems to take into account. However, still working on the conceptual level, the Menlo Park team could "disconnect" from certain areas (e.g.

generators or transmission) when focusing on finding the right filament. This can be quite advantageous under circumstances where a “reverse salient” (Hughes, 1983) hinders further development and concerted efforts are needed. There is also a notion of rationality and consciousness in the subjective form of knowing through concept formation that has gone somewhat missing in recent years research on practice-based organisational knowing. The formation of concepts requires some kind of mindful agent, who deviates from organisational routines (Nelson and Winter, 1982) or legitimate peripheral participation in a community of practice (Lave and Wenger, 1991; Brown and Duguid, 1991)

Fifthly, concept formation does not exist in a vacuum. Through its connections to other contexts of justification, concepts interact with other forms of knowledge and may be transferred (or translated). In the context provided in the narratives above, the objective knowledge of actually functioning devices and principles of physics and chemistry set obvious limitations to what concept that could be formed. However, concepts could be tested, tried and modified, as they were refined in sophistication and empirical content. New concepts could also alter the institutional rules of the game. How were people to behave in an “electrified world”? Through concepts and visions conveyed by public inventor-entrepreneurs as Edison and Westinghouse, ignition for change in institutional practices was provided years before actual apparatus were put in place. Finally, concepts in the early days of electrical engineering were intrinsically intertwined with bodily, emotional and cognitive dimensions of the men involved. Through internalisation of visions, work with prototypes and sketches, and experiencing the joys and disappointment would presumably have a deep impact of the tacit assent with which these people met and experienced their world.

Some of these points direct our attention to the important link between subjective knowledge and action i.e. how the concepts formed provide cues for further action (Weick, 1995). If concepts, metaphors, and models are to have implications not only for organisational foresight, but also for the shaping of the future, the link between what can be accomplished by the rational mind and the body needs to be further explored. As was pointed out by Polanyi (1946), the exploration of new discoveries relies on some kind of acceptance of authority. However, the curious mind wants to turn every stone and explore every scenario for possible futures. Where is the trade-off between what can be explored consciously and what can only be attained through focused search? Where does the generation of a multitude of incoherent, incompatible, but possible, conceptions of future scenarios lead us into a cul-de-sac? One avenue for exploring such dilemmas might be to align research programmes in organisational foresight to cognitive science to deepen our understanding of the human mind, responsible for so many good and devastating inventions.

References

Boisot, M. (1995), *Information Space: A Framework for Learning in Organizations*, London: Routledge

Bonjour, L. (1986), The Coherence Theory of Empirical Knowledge, in: P. K. Moser (ed), *Empirical Knowledge – Readings in Contemporary Epistemology*, Savage: Rowman & Littlefield Publishers

Brown J. S. and P. Duguid (1991), Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation, *Organization Science*, 2(1): 40-57

Brunsson, N. (1982), 'The Irrationality of Action and Action Rationality: Decisions, Ideologies and Organizational Actions', *Journal of Management Studies*, 19(1), 29-44

Carlson, W. B. (1991), *Elihu Thomson and the rise of General Electric, 1870-1900*, Cambridge, UK: Cambridge University Press

Cowan, R. and D. Foray (1997), The Economics of Codification and the Diffusion of Knowledge, *Industrial and Corporate Change*, 6(3): 595-622

Daft, Richard and Karl E. Weick (1984), 'Toward a Model of Organizations as Interpretation Systems', *Academy of Management Review*, 9(2): 284-295

Foray, D. and W. E. Steinmueller, (2001), *Replication of routine, the domestication of tacit knowledge and the economics of inscription technology: A brave new world?*, paper presented at the DRUID Nelson and Winter conference, Aalborg, Denmark

Foss, N. J., C. Knudsen and C. Montgomery (1995), An Exploration of Common Ground: Integrating Evolutionary and Strategic Theories of the Firm, in: Montgomery, C. A. (ed.), *Resource-Based and Evolutionary Theories of the Firm – Towards a Synthesis*, Boston, MA: Kluwer Academic Press

Fransman, M. (1994), Information, knowledge, vision and theories of the firm, *Industrial and Corporate Change*, 3 (3): 713-757

Friedel, R., Israel, P. and Finn, B. S. (1986), *Edison's Electric Light: Biography of an Invention*, New Brunswick, NJ: Rutgers University Press

Gentner, D. (1983), Structure-mapping: A theoretical framework fro analogy, *Cognitive Science*, 7: 155-170

Gentner, D. (1989), Mechanisms of analogical learning, in: S. Vosnadou and A. Ortony (eds.), *Similarity and analogical reasoning*, London: Cambridge University Press

Gentner, D. (2002), Analogy in scientific discovery: The case of Johannes Kepler, in: L. Magnani and N. J. Nersessian (eds.), *Model-based reasoning: Science, technology, values*, New York: Kluwer

Gentner, D and B. F. Bowdle (1994), *The Coherence Imbalance Hypothesis: A Functional Approach to Asymmetry in Comparison*, Proceedings of the 16th Annual Conference of the Cognitive Science Society: 351-356

Gentner, D, B. F. Bowdle, P. Wolff and C. Boronat (2001), Metaphor is like analogy, in: Gentner, D., K. J. Holyoak and B. N. Kokinov (eds.) *The analogical mind: Perspectives from cognitive science*, Cambridge: MA, MIT Press

Hughes, T. P. (1979), The Electrification of America: The System Builders, *Technology and Culture*, 20: 124–61

Hughes, T. P. (1983), *Networks of Power: Electrification in Western Society 1880-1930*, Baltimore, MD: The John Hopkins University Press

Hughes, T. P. (1989), *American genesis: A century of invention and technological enthusiasm, 1870-1970*, New York, NY: Viking Penguin

von Krogh, G. and J. Roos (1995), *Organizational Epistemology*, Hampshire: Macmillan

Lave, J. and E. Wenger (1991), *Situated Learning: Legitimate Peripheral Participation*, Cambridge: Cambridge University Press

Lehrer, K. (1974), *Knowledge*, Oxford: Clarendon Press

Loasby, B., 1993, Institutional change in the economy and science, in: Maki, U., B. Gustafsson and C. Knudsen (eds.), Rationality, institutions and economic methodology, Routledge

Losee, J. (1993), *A Historical Introduction to the Philosophy of Science*, 3rd edition, Oxford: Oxford University Press

Luhmann, N. (1995), *Social Systems*, Stanford: Stanford University Press

March, J. G. (1994), *A Primer on Decision Making: How Decisions Happen*, New York: Free Press

March, J. G. and J. P. Olsen, 1989. Rediscovering Institutions: The Organizational Basis of Politics, Free Press

Markman, A. B. (1997), Constraints on Analogical Inference, *Cognitive Science*, 21(4): 373-418

Morgan, M. (1999), Learning from models, in: Morgan, M. an M. Morrison (eds.) *Models as mediators: perspectives on natural and social science*, Cambridge: UK, Cambridge University Press

Nelson, R. R. (1991), 'Why Do Firms Differ, and How Does it Matter?', *Strategic Management Journal*, 12: 61-74

Nelson, R. R. and S. G. Winter, 1982. An Evolutionary Theory of Economic Change, The Belknap Press of Harvard University Press

Newton-Smith, W. H. (1981), *The Rationality of Science*, London: Routledge and Kegan Paul

Nonaka, I. (1994), A Dynamic Theory of Organizational Knowledge Creation, *Organization Science*, 5(1): 14-37

Nonaka, I. and H. Takeuchi (1995), *The Knowledge Creating Company*, New York: Oxford University Press

Nonaka I. and Konno (1998), The concept of "Ba": Building a foundation for knowledge creation, *California Management Review*, 40(3): 40-54

Passer, H. C. (1953/1988), *The Electrical Manufacturers 1875-1900: A Study in Competition, Entrepreneurship, Technical Change, and Economic Growth*, Cambridge, MA: Harvard University Press

Pappas G. S. and M. Swain (eds) (1978), *Essays on Knowledge and Justification*, Ithaca: Cornell University Press

Penrose, R. (1989), *The emperor's new mind*, Oxford University Press

Polanyi, M. (1946), *Science, Faith and Society*, London: Oxford University Press

Polanyi, M., 1983, The Tacit Dimension, Peter Smith

Prencipe, A. and F. Tell (2001), Inter-project learning: processes and outcomes of knowledge codification in project-based firms, *Research Policy*, Vol. 30, No. 9, pp. 1373-1394

Prout, H. G. (1921), *A Life of George Westinghouse*, New York, NY: The American Society of Electrical Engineers

Reber, A. S., 1993. *Implicit learning: an essay on the cognitive unconscious*, Oxford University Press

Rescher, N. (1993), *Pluralism – Against the Demand for Consensus*, Oxford: Clarendon Press

Ryle, G., (1949), *The concept of mind*, Hutchinson

Spender, J.-C. (1998), 'Pluralist Epistemology and the Knowledge-based Theory of the Firm', *Organization*, 19(2): 233-256

Teece, D., R. Rumelt, G. Dosi and S. Winter (1994), Understanding corporate coherence: Theory and evidence, *Journal of Economic Behavior and Organization*, 23: 1-30

Tell, F. (1997), *Knowledge and justification: Exploring the knowledge based firm*, Linköping University

Tell, F. (2000), What do organizations know? Different types of knowledge and the dynamics of justification contexts, the EGOS Colloquium, July 2-4, Helsinki, Finland

Toulmin, S. (1958), *The Uses of Argument*, Cambridge: Cambridge University Press

Tsoukas, H. (1993), Analogical Reasoning and Knowledge Generation in Organization Theory, *Organization Studies*, Vol. 14, No. 3, pp. 323-346

Tsoukas, H. (1996), The firm as a distributed knowledge system: A constructionist approach, *Strategic Management Journal*, 17 (Winter Special Issue): 11-25

Tsoukas, H. (1997), Reading organizations: Uncertainty, complexity, narrativity', address at the "Uncertainty, Knowledge, and Skill" Conference, 6-8 November, Limburg University

Tsoukas, H. and E. Vladimirou (2001), What is Organizational Knowledge?, *Journal of Management Studies*, 38(7): 973-993

Usselman, S. W. (1992), From Novelty to Utility: George Westinghouse and the Business of Innovation during the Age of Edison, *Business History Review*, 66: 251-304

Vincenti, W. G. (1990), *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, Baltimore: MD, The Johns Hopkins University Press

Weick, K. E. (1995), *Sensemaking in organizations*, Sage

Witt, U. (1998), Imagination and leadership: The neglected dimension of an evolutionary theory of the firm, *Journal of Economic Behavior and Organization*, 35: 161-177

Wittgenstein, L. (1953), *Philosophical Investigations*, Oxford: Basil Blackwell

Zollo, M. and S. G. Winter (2002), Deliberate Learning and the Evolution of Dynamic Capabilities, *Organization Science*, 13 (3): 339-352