Some issues in the philosophy of technology

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2016-04-18

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(From Sven Ove Hansson, "Science and technology: What they are and why their relation matters", pp 11-23 in Sven Ove Hansson (ed.) The Role of Technology in Science. Philosophical Perspectives. Dordrecht: Springer, 2015.)

2.1 Prehistory: The mechanical arts

In classical, medieval and early modern times, there was no talk of technology, and no concept corresponding closely to the modern term. The closest that we can some is the discussion expressed in terms of "art". The term "art" (ars) referred to all kinds of skills and abilities. It did not suggest a connection with what we today call the "fine arts" or just "art". The notion of art included "not only the works of artists but also those of artisans and scholars" (Tatarkiewicz 1963, 231)[1] The arts emphasized in knowledge classifications were the so-called "liberal arts". This is a term used since classical antiquity for the non-religious disciplines usually taught in schools, so called since they were the arts suitable for free men. (Chenu 1940. Tatarkiewicz 1963, 233.) Medieval universities had four faculties: Theology, Law, Medicine, and the Arts. The former three were the higher faculties to which a student could only be admitted after studying the liberal arts at the Faculty of Arts (also called the Faculty of Philosophy). (Kibre 1984)

Since the early Middle Ages, the liberal arts were usually considered to be seven in number, and divided into two groups. A group of three, called the "trivium" consisted of what we may call the "language-related" disciplines, namely logic, rhetoric, and grammar. The other group, the "quadrivium", consisted of four mathematics-related subjects, namely arithmetic, geometry, astronomy, and music. By music was meant a theoretical doctrine of harmony that had more in common with mathematics than with musicianship. (Hoppe 2011. Freedman 1994. James 1995. Dyer 2007.) Various authors made additions to the list of liberal arts, claiming that one or other additional activity should be counted as a liberal art. Not surprisingly, Vitruvius saw architecture as a liberal art, and Galen wanted to add medicine to the list. Others wanted to

[1] It was not until the eighteenth century that a literature emerged in which the fine arts were compared to each other and discussed on the basis of common principles. The term "fine arts" (in French "beaux arts") was introduced to denote painting, sculpture, architecture, music, and poetry, and sometimes others artforms such as gardening, opera, theatre, and prose literature. The decisive step in forming the modern concept of art was taken by Charles Batteux (1713-1780), professor of philosophy in Paris. In his book from 1746, *Les beaux arts réduits à un même principe* (The fine arts reduced to a single principle), he for the first time clearly separated the fine arts such as music, poetry, painting, and dance from the mechanical arts. (Kristeller 1980)

give agriculture that status, probably due to its association with a simple, innocent life. (Van Den Hoven 1996)

The liberal arts explictly excluded most of the activities undertaken for a living by the lower and middle classes. In antiquity such arts were called illiberal, vulgar, sordid, or banausic.[2] These were all derogative terms, indicating the inferior social status of these activities and reflecting a contemptuous view of physical work that was predominant in classical Greece (Van Den Hoven 1996, 90-91. Ovitt 1983. Tatarkiewicz 1963. Whitney 1990.) In the Middle Ages, the most common term was "mechanical arts".[3] It was introduced in the nineth century by Johannes Scotus Eriugena in his commentary on Martianus Capella's allegorical text on the liberal arts, *On the Marriage of Philology and Mercury*.[4] According to Johannes Scotus, Mercury gave the seven liberal arts to his bride, Philology, and in exchange she gave him the seven mechanical arts. However, he did not name the mechanical arts. (Van Den Hoven 1996. Whitney 1990.) Instead a list of seven mechanical arts, or rather groups of arts, was provided in the late 1120s by Hugh of Saint Victor:

1. lanificium: weaving, tailoring;
2. armatura: masonry, architecture, warfare;
3. navigatio: trade on water and land;
4. agricultura: agriculture, horticulture, cooking;
5. venatio: hunting, food production;
6. medicina: medicine and pharmacy;
7. theatrica: knights' tournaments and games, theater. (Hoppe 2011, 40-41)

The reason why Hugh summarized the large number of practical arts under only seven headings was obviously that he desired a parallel with the seven liberal arts. Hugh emphasized that just like the liberal arts, the mechanical ones could contribute to wisdom and blessedness. He also elevated their status by making the mechanical arts one of four major parts of philosophy (the others being theoretical, practical, and logical knowledge). (Weisheipl 1965, 65) After Hugh it became common (but far from universal) to include the mechanical arts in classifications of knowledge. (Dyer 2007)

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[2] Artes illiberales, artes vulgares, artes sordidae, artes banausicae.

[3] Artes mechanicae.

[4] De nuptiis Philologiae et Mercurii.

The distinction between liberal and mechanical arts continued to be used in the early modern era, and it had an important role in the great French *Encyclopédie*, published from 1751 to 1772, that was the most influential literary output of the Enlightenment. One of its achievements was the incorporation of the mechanical arts, i.e. what we call technology, into the edifice of learning. In the preface Jean Le Rond d'Alembert (1717-1783) emphasized that the mechanical arts were no less worthy pursuits than the liberal ones.

> "The mechanical arts, which are dependent upon manual operation and are subjugated (if I may be permitted this term) to a sort of routine, have been left to those among men whom prejudices have placed in the lowest class. Poverty has forced these men to turn to such work more often than taste and genius have attracted them to it. Subsequently it became a reason for holding them in contempt – so much does poverty harm everything that accompanies it. With regard to the free operations of the mind, they have been apportioned to those who have believed themselves most favoured by Nature in this respect. However, the advantage that the liberal arts have over the mechanical arts, because of their demands upon the intellect and because of the difficulty of excelling in them, is sufficiently counterbalanced by the quite superior usefulness which the latter for the most part have for us. It is this very utility which has reduced them forcibly to purely mechanical operations, so that the practice of them may be made easier for a large number of men. But society, while rightly respecting the great geniuses which enlighten it, should in no wise debase the hands which serve it." (d'Alembert 1751, xiij)

2.2 The modern term "technology"

The word "technology" is of Greek origin, based on "techne" that means art or skill and "-logy" that means "knowledge of" or "discipline of". The word was introduced into Latin as a loanword by Cicero (Steele 1900, 389).[5] However, it does not seem to have been much used until Peter Ramus (1515-1572) started to use it in the sense of knowledge about the relations among all technai (arts). The word became used increasingly to denote knowledge about the arts. In 1829 the American physician and scientist Jacob Bigelow published *Elements of Technology* where he defined technology as "the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science". (Tulley 2008) Already in

[5] Cicero, *Epistulae ad Atticum* 4:16.

the late seventeenth century "technology" often referred specifically to the mechanical arts and the skills of craftspeople. (Sebestik 1983) This sense became more and more dominant, and in 1909 *Webster's Second New International Dictionary* defined technology as "the science or systematic knowledge of industrial arts, especially of the more important manufactures, as spinning, weaving, metallurgy, etc." (Tulley 2008) This means that technology was no longer conceived as knowledge about *techne* in the original Greek sense of the term, i.e. arts and skills in general. It had acquired a more limited sense referring to what is done with tools and machines.

This delimitation of techne and technology excludes many skills (or "productive arts"). We do not usually use the term "technology" to refer to knowledge about the skills of a physician, a cook, or a musician. On the other hand we tend to use the term about computer programming and software engineering. The delimitation of skills counted as technological appears rather arbitrary, in much the same way as the exclusion of history and art theory from science appears arbitrary. Arguably, the Aristotelian sense of "ars" (or "techne") is more principled and coherent than the modern delimitation of "technology".

But in the English language the word "technology" also acquired another meaning that became more and more common: Increasingly it referred to the tools, machines, and procedures used to produce material things, rather than to science or knowledge about these tools, machines, and procedures. This usage seems to have become common only in the twentieth century. The earliest example given in the Oxford English Dictionary is a text from 1898 about the coal-oil industry, according to which "a number of patents were granted for improvements in this technology, mainly for improved methods of distillation". (Peckham 1898, 119) Today this is the dominant usage. As Joost Mertens noted, "[i]n English usage, 'technology' normally refers to instrumental practices or their rules and only exceptionally to the scientific description, explication or explanation of these practices." (Mertens 2002) However, this is not true of all languages. For instance, French, German, Dutch, and Swedish all have a shorter word (technique, Technik, techniek, teknik) that refers to the actual tools, machines and practices. In these languages, the word corresponding to "technology" (technologie, Technologie, technologie, teknologi) is more often than in English used to denote knowledge about these practical arts rather than to denote these arts and their material devices themselves. However, due to influence from English, the use of "technology" in the sense of tools, machines and practices is common in these languages as well. (According to the *Svenska Akademiens Ordbok*, the Swedish counterpart of the OED, this usage seems to have become common in Swedish in the 1960's.)

3 What is technological knowledge?

From Sven Ove Hansson "What is technological knowledge?", pp. 17-31 in Inga-Britt Skogh and Marc J. de Vries (eds), Technology Teachers as Researchers, Sense Publishers 2013.

3.1 Introduction

As usual, Joanne goes to work by bicycle. She is an engineer in a medium-sized company in the automatic control industry. The first thing she does after putting down her bag in her office is to make a pot of tea for herself and her closest colleagues. She pours four teaspoons of black tea into the pot, one for each person and one for the pot. After bringing a cup of tea to her own desk she begins the days work. Her first task is to study a report from the companys laboratory. The technicians have tested the first prototype of a new thermostat that she has designed. Unfortunately the device did not respond rapidly enough to changes in temperature. In order to solve the problem she pulls out a couple of handbooks in thermodynamics from her bookshelf and starts to calculate the effects of several alternative designs.

In this short episode we find examples of four types of technological knowledge. The first is her ability to ride a bicycle. Most cyclists cannot tell how they keep balance on a bicycle. (Jones 1970) Such knowledge is called tacit. It has an important role in many types of craftsmanship and professional knowledge. Painters can seldom explain the hand movements by which they even out a surface much faster, and with much less spackling paste, than an amateur. The skilled lab nurse will find it equally difficult to explain to an inexperienced colleague how to take blood samples from patients with difficult veins.

When Joanne made tea she applied a traditional rule for measuring out tea leaves. Probably she does not know its background. She uses it because it works (gives suitably strong tea). This can be called practical rule knowledge. It differs from tacit knowledge in being expressible in words. She has in fact taught it to her five year old son (who is still not able to ride a bicycle). Joanne also makes abundant use of rule knowledge in her work as an engineer. When she designs a load-bearing part she always makes it strong enough to carry twice the intended load. This is a practical and reasonably simple way to ensure that her constructions do not break, but there is no theoretical ground for choosing 2 as a safety factor. (Doorn and Hansson 2011)

When she studies the lab report she (and her colleagues in the laboratory) apply scientific methodology to investigate a technological object. This is technological science. Advanced engineering often proceeds in this way, i.e. technological constructions are investigated with scientific methodology. This means that the same methods are used as in the natural sciences to ensure a reliable result: control groups, randomization, blinding, control measurements, well-calibrated measurement instruments etc. But technological science differs from natural science in having man-made rather than natural objects of study.

Finally, when she applies thermodynamics to design a better thermostat she makes use of natural science to solve a technical problem. This is a type of problem solving that her education has made her well prepared for. Engineering education includes considerable amounts of natural science and training in its application to technological problems. But ten years ago, when working so hard with her course in thermodynamics, she had no idea that one day she would apply it almost on a daily basis.

3.2 Four types of technological knowledge

In summary we have four major types of technological knowledge: tacit knowledge, practical rule knowledge, technological science, and applied (natural or social) science. This is by no means the first attempt to classify technological knowledge; quite a few typologies and catalogues have already been published. (For an overview, see Houkes (2009, pp. 321-327) There are two major reasons why I have chosen to propose a new typology instead of applying one that is already available. One reason is that previous typologies have been based on mixtures of several criteria for the classification; some typologies contain both types defined in terms of what is known and types defined in terms of how something is known. The present proposal focuses on how we know, not on what we know. (I will return below to the possibility of combining these two crossing distinctions to obtain a more detailed typology.)

The other reason is that previous typologies did not seem to be well suited to educational needs. As we will soon see, the four types in this typology are acquired by different learning processes, which makes the typology relevant for studies of teaching and learning.

As shown in Figure 1, the four types can be linearly ordered in terms of how practical or theoretical they are. Tacit knowledge is decidedly non-theoretical. It is followed by practical rule knowledge that is somewhat more "theoretical" since it is expressed in words. The two types of science represent more theoretical types of knowledge. Since technological science is focused on making things work, we can describe it as less theoretical than natural and social sciences that focus on explanations.

3.3 Tacit knowledge

The expression "tacit knowledge" is fairly new; it was introduced by the Hungarian-British chemist and philosopher of science Michael Polanyi (18911976). His book *The Tacit Dimension* from 1966 is still the starting-point of many discussions on tacit knowledge. However, his main interest was natural science rather than technology or technological science. He wanted to show that a strictly rule-bound road to scientific knowledge does not work; there is always an element of intuitive human judgement.

Today, technological knowledge is at the centre of the discipline of knowledge management that was established at the beginning of the 1990s. The Japanese researcher Ikujiro Nonaka (born in 1935) has had a leading role in applying Polanyis concept to practically oriented management and organization research. His main focus is on how tacit knowledge can be transferred from one person to another. There are two major methods for this. One is apprenticeship: the learner observes and tries to imitate someone who already possesses the tacit knowledge. In this way she can often herself develop the same type of tacit knowledge. The other method is based on prior articulation (externalization) of the tacit knowledge, i.e. it is described in words so that others can learn it more easily. (Nonaka and Takeuchi 1995. Nonaka and von Krogh 2009.)

Nonaka and his co-workers emphasized the latter method, the articulation of tacit knowledge in language. They provided a famous example of this: the development of the first bread-making machine for household use that was launched in 1987. (Nonaka och Takeuchi 1995) The early prototypes did not produce bread of sufficient quality. In order to improve the machine, the designers had to find out how to knead a dough. Unfortunately this could not be learnt from books; it was tacit knowledge that one has to learn from a baker. To solve the problem a member of the design team apprenticed with a master baker at a luxury hotel. The baker was unable to tell her in words what to do, but she tried to imitate him and in this way she gradually learnt the right movements. Finally she managed to express what she had learnt in words: a twisting stretch was required. She and her colleagues in the design team managed to construct a machine that performed a twisting stretch and baked (sufficiently) good-tasting bread.

The articulation of tacit knowledge in the form of instructions and descriptions has been performed with at least three different purposes. The first of these is examplified by the bread-making machine: the mechanization and automatization of a work process. Since the industrial revolution, the articulation of tacit knowledge has been an important part of the mechanization of work tasks previously performed by craftspeople. Today, such articulation of tacit knowledge often takes the form of computer programming.

The first step in programming is often to develop a detailed description of how a human expert performs a task. This description can then be codified into a computer programme.

The second purpose is to facilitate teaching and learning. Learning a craft or profession would be incredibly inefficient and time-consuming if every learner had to repeat the mistakes of her predecessors. Suppose that the tasks to be performed in the control room of a nuclear plant could only be learned in an intuitive, trial-and-error fashion. It would then be a much more precarious task to train a new generation of operators than if most of the knowledge they need is available in written form. The authors of textbooks for crafts and professions spend considerable efforts on articulating the tacit knowledge of experienced practitioners as far as possible.

The third purpose of articulating tacit knowledge is to control other peoples work. Ever since the industrial revolution employers have systematically divided qualified tasks into simpler subtasks, most of which can be performed by cheaper labour. The extensive (tacit and explicit) knowledge of highly qualified workers has been codified and divided into small tasks that can more easily be taught and learnt. The assembly line is the most well-known example of this process. The American Frederick Taylor (18561915), the pioneer of the so-called scientific management movement, saw this dequalification of labour as a major purpose of new management practices. All possible brain work should be removed from the shop and centered in the planning or laying-out department. (Taylor [1911] 2008, 50). But ever since the early days of the industrial revolution, critics, including Adam Smith (1776, V:i:ii) and Karl Marx (1867, I:12.5), have warned against the resulting deterioration of the quality of working life. (Cf.: Braverman 1974. Campbell 1989, 226. Wood 1982. Wood 1987.) However, it should be noted that this criticism has not been targeted at the articulation of tacit knowledge but at the use of this articulation to change the work process in ways contrary to the interests of workers.

On some occasions, tacit knowledge has been romanticized and described as a better type of knowledge that should be kept tacit rather than being articulated. In my view this is not a tenable position. We humans have developed language in order to convey insights, instructions, and other messages to each other. By articulating previously tacit knowledge we make it accessible to criticism, evaluation, and improvement. If physicians choose treatment methods intuitively (which previously was the ideal, cf. Wootton 2006) it will be exceedingly difficult to evaluate and improve their treatments. In contrast, if they apply precisely described criteria for diagnosis and treatments, then such evaluation and improvement can be performed in a systematic fashion. Both tacit and explicit knowledge can be in error, but explicit knowledge is more easily corrigible since it is more accessible to critical discussion and evaluation.

In other words: Tacit knowledge that is valuable does not become less valuable when expressed in words. To the contrary, language is needed to transmit, evaluate, and improve knowledge. In some cases complete articulation may not be possible, but partial articulation may still be better than no articulation at all.

3.4 Practical rule knowledge

The second main form of technical knowledge is practical rule knowledge. Much technical knowledge is taught and learned in this form, not least in practical crafts. The practical knowledge of electricians is a good example of this. There are many rules for how to connect wire. Many of these rules have a theoretical justification, but in practical work the electrician does not refer to these justifications but to the rules that are based on them. There are for instance good reasons not use certain types of cable for tensions above 250 V, but the electrician applies the rules, not the underlying theory. Furthermore, many of these rules are based on a combination of theoretical justifications and convenient conventions. There are good reasons to use one and the same colour code for all earth wires, but the choice of green and yellow for that purpose is a convention that cannot be derived from physics.

Rules of this type are often called rules of thumbs. A major characteristic of such rules is that they are easy to memorize and apply. The term rule of thumb has been in use at least since the latter part of the 17th century. Its origin is unclear, but one plausible hypothesis is that it derives from the use of the thumb as a unit for length measurement. (At least since the seventeenth century an inch has also been called a “thumb’s breadth”. In many languages, including French, Spanish, Swedish and Dutch, the word for inch is derived from that for “thumb”.)

Although rules of thumb are used extensively in practical technical work, surprisingly little has been written about the ways in which they provide us with knowledge. Per Norström (2011) has recently compared rule of thumb knowledge with other forms of technological knowledge. He started out from his own experience as an engineer working with PID controllers (proportionalintegralderivative controllers) that are used to regulate the flow of liquids through pumps. On his former workplace there were two experts in the calibration of PID controllers, Paul and Nils. Both were highly skilled, but they worked in very different ways. Paul had remarkably accurate intuitions about the instruments, but he could never explain his intuitions or tell others how to calibrate an instrument. Nils performed the work with the help of mathematical calculations that he was happy to teach anyone who wanted to learn them, but that learning process would take some time. On one occasion when neither of them was available, Per had to step in and calibrate a PID regulator. Since he had neither Pauls intuitions nor Nilss skill in calculation methods he consulted a handbook. It contained a simple rule in the following style:

> Set all parameters in zero position. Raise the Kp control until oscillation starts. Then lower the Kd control until the oscillations stop.

Thus, Per employed a rule of thumb that had the considerable advantage that it could be learnt quickly. But he was aware that if something unusual happened, or if he were confronted by another type of regulator, then the rule of thumb could not be trusted. Chances would be much higher that Nils could have solved such a situation with his calculations. Rules of thumb tend to have a much smaller area of application than scientific knowledge.

Rules of thumb can have different origins. Some of them are the result of articulation of tacit knowledge. Others have been obtained through simplification of scientific knowledge. In yet other cases they are based on a combination of scientific knowledge and experience-based safety margins. This applies for instance to many of the rules that are used in engineering design.

3.5 Technological uses of science

Technological science, in the limited sense in which I use this term here, is science that systematically investigates different technological solutions in order to find out their properties. Just as natural science, technological science employs experiments as a primary source of knowledge. In fact, technological experiments have a much longer tradition than experiments in natural science. They can be traced back to the experimental traditions that have been found among indigenous peoples. The Mende people in Sierra Leone even has a special word, “hungoo”, for experiment. A hungoo can for instance consist in planting two seeds in adjacent rows, and then measuring the harvests in order to determine which seed was best. Hungoos are probably a native tradition, not one brought to the Mende by visiting Europeans. They are definitely technological experiments, not natural science experiments, since their purpose is to find out how to achieve certain practical ends, not to understand nature. Similar experiments also occur in other parts of the world.

(Richards 1989). Through the centuries, technological development has largely been driven by craftspeople systematically trying out different constructions and methods.

The experimental tradition among craftsmen was one of the major sources of modern scientific methodology. Galileo Galilei (1564-1642) and other scientific pioneers learned much from skilled workers on the art of extracting information from nature by manipulating it, i.e. making experiments (Drake 1978, Zilsel 1942). But from the very beginnings experiments in the natural sciences had another goal than technological experiments. Craftspeople made experiments in order to solve technical problems, natural scientists in order to find out the workings of nature.

The experimental tradition in the crafts continued to develop in parallel with natural science. In the 18th and 19th century millwrights performed advanced experiments and measurements, but they had little or no contact with the academic science of their times (Layton 1978). It was not until the latter part of the 19th century that natural science was employed on a large scale to develop new technology. The chemical and electrotechnical industries were the pioneers in this new development. Important inventions such as the telegraph were the outcomes of discoveries in university laboratories. (Böhme 1978. Kaiser 1995.) But in some technological areas, technology development continued well into the 20th century to have little or no contact with natural science. This applied for instance to metallurgy; new methods were tried out and tested in ironworks, based on experience rather than on principles and ideas from the natural sciences (Knoedler 1993).

In the 19th and early 20th century, schools of engineering fought to obtain the same status as universities. To prove their case they had to base their teaching of technology on a scientific basis. Two different strategies were adopted to achieve this. One was to use results from the natural sciences to investigate the workings of machines and other technological constructions. Formulas from mechanical science were used to characterize the movements of machine parts, and the theory of electromagnetism was applied in the construction of electric machines and appliances. New disciplines, such as structural mechanics, were developed that broadened the basis of this type of calculations. This development has intensified over the years. Today, new physics and chemistry give rise to more and more sophisticated technology. The technological use of biological science is increasingly common, and so is that of the social and behavioural sciences (for instance in the construction of entertainment technologies and human-machine interfaces).

The other strategy was to apply scientific method directly to technological constructions. Machines and machine parts were built, and measurements were made on alternative constructions in order to optimize their performance. (Faulkner 1994. Kaiser 1995.) In many cases, this was the only way to solve practical technological problems. (Hendricks et al 2000) The processes studied in wind tunnels were usually too complex to allow for a mathematical solution. Direct testing of technological constructions has continued to be an essential part of scientific engineering. Without crash tests, automobile safety would have been much worse. Even when a construction is based on relatively simple, well-known principles, it has to be tested in practice. Endurance tests of furniture and household appliances are among the best-known examples of this.

These two traditions, technological science (in a strict sense) and applied natural science, are still alive and well at technological universities. Today few would deny that they are both needed and that they complement each other.

Even if we run technologies on a daily basis with tacit knowledge and/or practical rule knowledge, when something goes wrong we tend to turn for science for a solution. A scientific approach or at least a science-based understanding of mechanisms is often necessary in troubleshooting. An operator in the control room of an advanced technological system cannot respond adequately to unforeseen deviations unless her knowledge of the system goes far beyond practical rule knowledge.

3.6 Characteristics of technological science

Technological science is much less discussed than natural science, and it is often seen as a variant of natural science. In fact it differs from natural science in several important respects. These can be summarized in the form of six distinguishing characteristics of technological science. (Hansson 2007)

First and perhaps most obviously, the technological sciences differ from most of the natural sciences in that their study objects have been constructed by humans, rather than being objects from nature. This is a basic difference, but a clarification and an exception have to be made.

The clarification is that this difference refers to the ultimate study objects of the respective disciplines. Natural scientists often study objects that have been modified for the purpose of measurement or experiment, but this is done only as a means to understand objects or phenomena that occur naturally. As one example of this, in order to determine the structure of a protein it is often useful to produce a crystallized form of it. Spectroscopic studies are then performed on the crystallized protein in order to determine its structure. Obviously, the crystallized protein is not a naturally occurring object but one that has been modified by humans. However, for the biochemist the crystallized protein is not the ultimate study object. It is studied in order to understand the structure and the workings of the naturally occurring protein. In contrast, the human constructions studied by technological scientists, such as machine parts and computer programs, are their ultimate study objects.

The exception is chemistry that differs from the other natural sciences in this respect. Most of the substances studied by chemists are not known to occur in nature.

The second characteristic is closely connected with the first one: The design of new technological objects is an essential component of engineering. Design is also an important part of the work of many academics in the technological sciences. Technological scientists do not only study human-made objects, they also construct them.

Again, a caveat concerning chemistry is needed: Synthetic chemistry is similar to the technological sciences in that it aims at the construction of new objects (in this case, new chemical substances). (Schummer 1997) There is, however, an important difference between chemical synthesis and engineering design. Chemical synthesis is aimed at obtaining a substance with a specific, predetermined molecular structure. In contrast, engineers designing a new product work with a complex and often not fully explicit list of design specifications or goals. The ideal outcome of the design process would be a product that fully satisfies all the design goals. In practice, however, such an outcome is seldom achieved. Compromises and trade-offs between conflicting design criteria have to be made in the course of the design process. (Asimov 1974. Vincenti 1990. Vincenti 1992.)

Engineering design has an important role in the development of new experiments in the natural sciences. It is common for new experiments to depend crucially on the design and production of new experimental equipment. From this point of view, the natural sciences are in part based on the technological sciences, just as technology is in part based on the natural sciences. (Janich 1978. Kroes 1989. Lelas 1993.)

The third characteristic is that the study objects of technological science are largely defined in functional terms. In order to determine if an object is a screwdriver we have to determine whether it has the function of driving screws. Therefore, screwdrivers are a functional category. The same applies to object categories such as saws and diodes, ladders and lamps, refrigerators and particle accelerators. These are all functional categories. The functions that define these and other classes of technical objects serve as conceptual bridges between human intentions and the physical world. (Kroes and Meijers 2002. Hansson 2002. Hansson 2006.

Vermaas and Houkes 2006. Kroes 2006,)

Again, an exception has to be made. There is one of the natural sciences, namely biology, in which functions have a central terminological role. Concepts such as fin, eye, gland, stem, flower, and food are all defined according to their functions for the organism. The major difference is of course that whereas technological functions have been intentionally assigned to objects, biological functions are our way to describe the outcomes of evolutionary processes.

The fourth characteristic is that the conceptual apparatus of the technological sciences contains a large number of value-laden notions. (Layton 1988) Concepts abound that have a clear value component (user friendly, environmental friendly, risk, safety, disaster...) We have explicit technological norms in the form of written codes and standards that provide us with detailed specifications for a wide variety of technological products, practices, and procedures. Most importantly, evaluations of technological objects have a central role in technological science and research. We perform research in order to construct better bridges, cars, computers, computer programs, medical implants, etc. Contrary to natural scientists, technological scientists freely evaluate their study objects in value terms. In this respect they are close to medical scientists, who feel no need to make their science value-free by eliminating references to better treatments or bad developments of a disease. In this respect, technological science is also closer to the social than the natural sciences. Value-laden concepts such as "justice", "welfare" etc. have a central role in several of the social science disciplines.

The fifth characteristic is that technological science has less room than the natural sciences for idealizations. In the natural sciences, far-reaching idealizations are made in order to isolate natural phenomena from each other. (McMullin 1985) A physicist who studies electromagnetism uses models of electromagnetic phenomena in which gravitation is absent. Similarly, in studies of gravitation she will use models in which there are no electromagnetic forces. Often, scientific experiments are performed under specially constructed conditions that are tailored to suit such simplified models. Physical experiments are often performed in vacuum in order to correspond to theoretical models in which the impact of atmospheric pressure has been excluded. Chemical experiments are performed in gas phase in order to ensure that each pair of reacting molecules has no interaction with other molecules. This brings these experiments into closer correspondence to theoretical models of reaction mechanisms.

All this works well in the natural sciences, but it does not work for engineering. The physicist can use a theory of electromagnetism that does not take gravitation into account, but the engineer who constructs an electric motor for an elevator cannot disregard the effects of gravitation unless the machine is intended for use in a space station. Similarly, theoretical mechanics does not take weather conditions into account. In the construction of a suspension bridge the same idealization can lead to disaster. (Layman 1989)

The sixth and last characteristic concerns the attitude to mathematical problem-solving. Both in the natural and technological sciences, many problems refer to measurable quantities and require a mathematical solution. There is, however, an important difference in the very nature of the precision requirement. The precision that the engineer needs is always obtainable by means of a sufficiently good approximation. Thus, if the choice of wire dimensions for a suspension bridge depends on the solution of a complex system of equations, the engineer does not need an analytical solution of the system; if a solution has been obtained with a sufficient number of decimals the problem has been solved. In this she differs for instance from an astrophysicist or a population geneticist who needs to solve an equally complex system of equations. For the purposes of the natural sciences, an analytical solution is always preferred (although there are areas, such as quantum chemistry, in which it is seldom obtainable). This may partly be a matter of the aesthetic qualities of the solutions, but it is also a matter of their explanatory qualities. There is a good chance that the insights obtainable from an exact solution can contribute to the solution of other similar problems in the future.

3.7 Transformations between the four knowledge types

As already indicated, the four types of technological knowledge can be ordered linearly according to how practical or theoretical they are. This also makes it possible to systematize the different ways in which one type of knowledge can be transformed into another. This is illustrated in Figure 2.

We can divide knowledge transformations into two major groups depending on whether they transfer knowledge to a more theoretical type (a movement to the right in the diagram) or a more practical type (a movement to the left).

One type of transformation to more theoretical knowledge has already been mentioned, namely the articulation of tacit knowledge that then becomes practical rule knowledge (arrow 1 in the diagram). When a transformation in the theoretical direction results in (technological or applied) science, we can call it a scientification of knowledge. An explanation of bicycle riding in terms of physics is a case of scientification (arrow 2 in the diagram). Another example is the development of theories about heat engines into more general of thermodynamic theory (arrow 3 in the diagram).

Next, let us consider transformations in the other direction, i.e. to more practical knowledge. An important group of such transformations are those that result in tacit knowledge. It is usually practical rule knowledge that is starting-point for such a transformations. It can be called a routinization (arrow 4). One typical example is when a young car-driver learns to gear up or down without thinking of it. Another example of routinization is learning to play a musical instruments. In these and many other cases the routinization of practical rule knowledge is necessary to make us able to perform various tasks without too much delay or effort.

Other transformations in the theoretical-to-practical direction are those that result in practical rule knowledge or in technological science. These transformations can be described as the application of science. The rules of thumb that Per Norstrm used to calibrate a PID regulator must have originated in application of either technological or natural science (arrow 5 or 6).

3.8 Learning

The four knowledge types differ substantially in how easy or difficult they are to learn. This is schematically illustrated in Figure 3, where the thickness of arrows illustrates the ease with which the different knowledge types are learnt. It must be emphasized that actual learning processes are much more complex than the transfer of a piece of knowledge from teacher to student that is depicted in the diagram. The communication between student and teacher is almost always bidirectional, and communications with others than the teacher (such as fellow students) are often essential for the learning process. However, the diagram illustrates one central feature of learning, and one in which the four types of technological knowledge differ in important respects.

As indicated in the diagram, practical rule knowledge is by far the knowledge form that is easiest to learn. It is followed by technological and applied science. Learning science takes much more effort than learning rules of thumb. All these three can be taught by conventional methods in which verbal instructions and explanations have a central role. By far the most difficult type of knowledge to learn is tacit knowledge that cannot be taught by verbal instruction. As discussed above, tacit knowledge can be acquired through imitation attempts in apprenticeship, but in many cases that is a difficult and uncertain procedure.

Fortunately, there is an alternative way to learn tacit knowledge: In many cases it can be articulated to practical rule knowledge, which is then taught in the usual way in which verbal instruction has an essential role. This results in practical rule knowledge that can then finally be routinized through training. This three-step procedure for acquiring tacit knowledge is illustrated in another schematic diagram, Figure 4.

In summary we have five learning processes for technological knowledge:

- Tacit knowledge through imitation. (Leftmost arrow in figure 3.)
- Tacit knowledge through articulation, verbal instruction, and routinization. (Figure 4.)
- Practical rule knowledge through methods in which verbal instruction has an essential role. (Second arrow in figure 3.)
- Technological science through methods in which verbal instruction has an essential role. (Third arrow in figure 3.)
- Applied science through methods in which verbal instruction has an essential role. (Rightmost arrow in figure 3.)

3.9 A combined classification scheme

The fourfold classification of technological knowledge refers to how one knows, not to what one knows. Alternatively, we can classify technological knowledge according to its contents, i.e. to what one knows. Such a classification would have to contain categories such as: knowledge about how to construct an artefact, knowledge about how to use an artefact, knowledge about (and ability to explain) how an artefact works, etc. Table 1 gives an indication of how these two ways to classify technological knowledge can be combined. As the table illustrates, some knowledge contents can be known in different ways. It is proposed that this two-dimensional classification can be useful for practical teaching. You need to know what type of knowledge you want the student to acquire in order to determine how to teach. The reader is invited to add more rows to the column, illustrating different types of technological knowledge that students are required or encouraged to acquire.

3.10 Discussion

In summary we have identified four major types of technological knowledge: tacit knowledge, practical rule knowledge, technological science and applied (natural and social) science. Technology educations differ in the relative emphasis that they put on each of these knowledge forms. Education for practical crafts will usually put more emphasis on tacit knowledge and practical rule knowledge, whereas engineering education puts more emphasis on the two scientific knowledge forms. Basic technology education in compulsory schools should presumably aim at some sort of balance between the four in order to provide a basic understanding of how practical and theoretical knowledge is combined in technology. Within the limited time allotted to technology in most educational systems, this is no easy task.

One of the factors that complicate this task is the lack of technology teachers who are sufficiently acquainted with all four types of technological knowledge. In Sweden, the introduction of technology education in primary school led to a conflict between crafts (sloyd) teachers and physics teacher, who both wanted to teach the new subject. This was a clash between teaching professions that represent different types of technological knowledge. Crafts teachers represent both tacit knowledge and practical rule knowledge. Learning how to hit the nail and not your own fingers with the hammer is for the most part an acquisition of tacit knowledge. Learning which types of saw or knitting needles to use for different purposes is much facilitated by rules of thumb. Physics teachers, of course, represent natural science. A physics teacher is well equipped to teach students how the laws of physics can be used to understand and predict the behaviour of technological objects such as electric motors, binoculars, and pulleys. Neither crafts teachers nor physics teachers tend to be knowledgeable in technological science. And most importantly, neither of them has the education needed to teach how the four types of knowledge meet in technology.

But this is a difficulty that can be turned into a strength. Technology education can become a meeting place for different types of knowledge. It can be a place where students begin to understand the relationships between theoretical and practical knowledge. It can thereby also become a source of understanding and respect for the different types of knowledge that are needed to build a society. For this to succeed we need technology teachers with broad knowledge and understanding of both the theoretical and the practical forms of technological knowledge.

	Tacit knowledge	Practical rule knowledge	Technological science	Applied science
ability to ride a bicycle	+	–	–	–
ability to shift gears in a car	+	(+)	–	–
ability to construct a suspension bridge	–	+	+	(+)
ability to determine the aerodynamic properties of a new car model	–	–	+	(+)
ability to explain how one rides a bicycle	–	–	–	+

Table 1: Combined classification of technological knowledge, referring both to how the person knows and what she knows. + denotes appropriate, (+) partly appropriate and inappropriate form of knowledge for the knowledge contents in question.

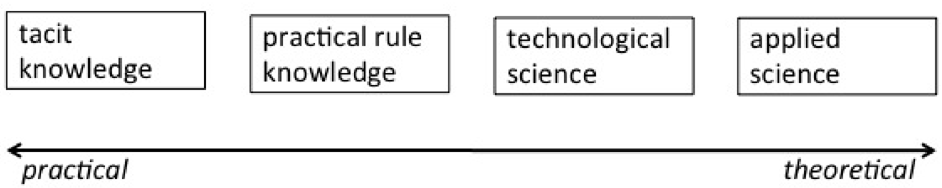

Figure 1: Figure 1. The four types of technological knowledge, ordered in the practicaltheoretical dimension.

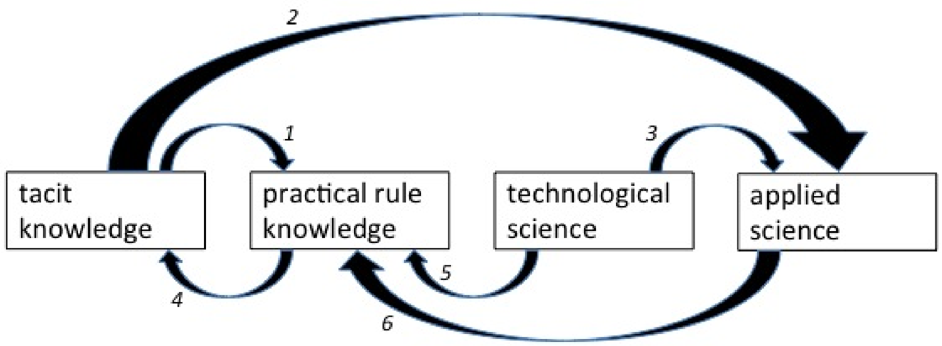

Figure 2: Figure 2. Transformations of technological knowledge: articulation (1), scientification (2 and 3), routinization (4) and application (5 and 6).

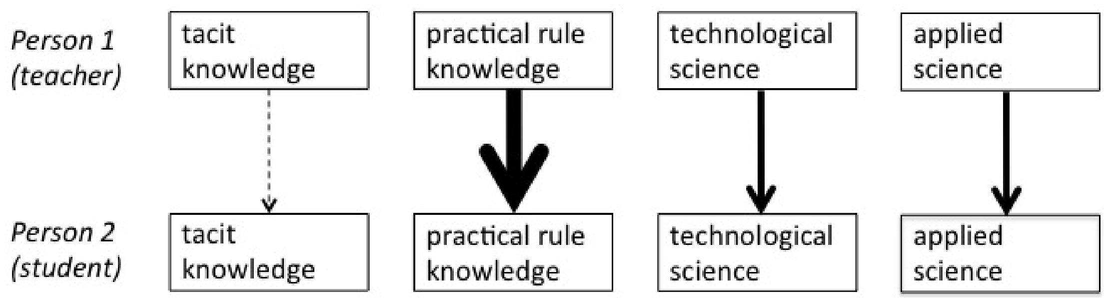

Figure 3: Figure 3. Schematic representation of direct learning processes for technological knowledge. The dashed arrow represents imitation whereas the solid arrows represent methods in which verbal instruction has an essential role. A thicker line denotes more efficient learning.

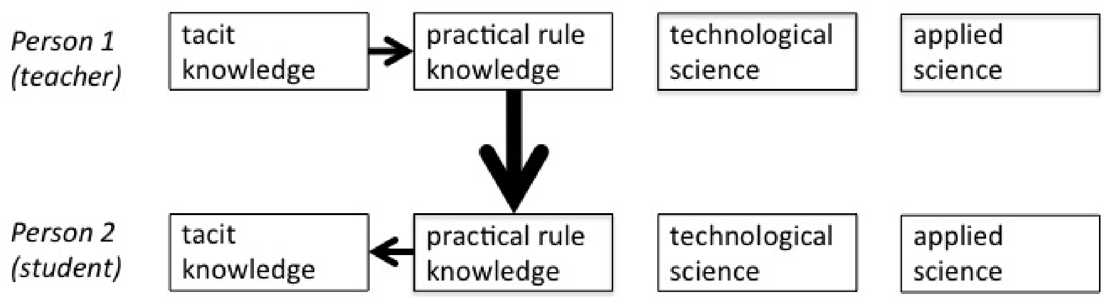

Figure 4: Figure 4. Schematic representation of an indirect learning process for tacit knowledge.

4 What is technological science?

(From Sven Ove Hansson "What is Technological Science?". Studies in History and Philosophy of Science, 38:523-527, 2007.)

4.1 Introduction

Departments of engineering often describe their own activities as "technological science". A Google search of "technological science(s)" in early September 2006 resulted in 251 000 hits, many of which confirmed that the phrase is commonly used in the names of university departments, academies, and other academic organizations. But what is technological science, and is it really different from the natural sciences?

Historically, the emergence of self-conscious technological science took place in parallel with the "scientification" of medicine. An interesting comparison can be made between the two disciplines. Although medicine has been studied at universities since the late thirteenth century, it was not until the nineteenth century that professors of medicine strove to make their discipline one of the sciences. Two major approaches were taken to achieve this. One was to make medicine essentially a branch of the natural sciences. By studies in the laboratory, diseased organs and tissues could be classified and causes of disease could be revealed. Claude Bernard was a leading proponent of this approach to the scientification of medicine. The other approach was to perform treatment experiments, i.e. what we today call clinical trials. In the nineteenth century the first pioneers of clinical research began to evaluate the effectiveness of therapeutic methods through statistical comparisons of groups of patients who had received different treatments. (Booth, 1993. Wilkinson, 1993. Feinstein, 1996.) Originally, the two approaches to scientific medicine were conceived by their respective proponents as competitors. Today it is generally recognized that laboratory research is as necessary to develop new therapies as is clinical research to evaluate, validate, and calibrate them.

University education in technology and engineering is of much more recent origin than that in medicine. Higher technological education in Europe has its origin in the polytechnical schools of the 19th century, the first being the École Polytechnique in Paris (1794). It was largely in the higher institutes for engineering of the 20th century that the struggles for making studies in technology recognized as science took place. The struggle was eventually successful; in the first half of the 20th century, German institutes of technology were given the right to award a doctors degree, and in the second half of that century most of them were renamed universities.

Two strategies were used by these institutions to make studies in technology more scientific and thereby also improve their own status, with the goal of being recognized as universities. These two strategies correspond closely to the two strategies of medical research just referred to. One was to use results from the natural sciences to investigate the workings of machines and other technological constructions. Formulas from mechanics were used to characterize the movements of machine parts, and the theory of electromagnetism was used in constructing electric machines and appliances. New disciplines, such as structural mechanics, were developed that broadened the basis of this type of calculations. This development has continued, and new physics and chemistry have given rise to more and more sophisticated theory-based technological constructions. This corresponds to the development of laboratory research in medical science.

The second strategy was to apply scientific method directly to technological constructions. Machines and machine parts were built, and measurements were performed on alternative constructions in order to optimize their construction. (Faulkner, 1994. Kaiser, 1995.) In many cases, this was the only way to solve practical technological problems. (Hendricks et al, 2000) The processes studied in wind tunnels were usually too complex to allow for a mathematical solution. Direct testing of technological constructions has continued to be an essential part of scientific engineering. Without crash tests, automobile safety could not have reached its present level. Even when a construction is based on relatively simple, well-known principles, it has to be tested in practice. Endurance tests of furniture and household appliances are among the best-known examples of this.

Whereas the first of the two strategies can be described as applied natural science, the second does not fit well into that description. Instead of using results from the natural sciences, scientific investigations are performed that relate directly to practical problems (Hansson, 2006c). Due to the essential role of this type of investigation in all branches of technological science, it would be grossly misleading to describe technology or technological science as applied natural science. Engineers who develop or evaluate new technology have much more to do than applying results from the natural sciences. (Layton, 1978)

It is the purpose of the present paper to identify the major characteristics of technological science that distinguish it from other types of science. I will propose six such characteristics, two each in the three categories objects of study, basic concepts, and theoretical models. None of these provides a perfectly sharp distinction between technological and other sciences, but in combination they show that technological science is a distinctly different form of activity than other sciences, such as natural science that is probably its closest likeness.

4.2 Objects of study

With respect to their objects of study, the technological sciences differ in at least two ways from the natural sciences.

4.2.1 Human-made objects

The most obvious way in which the technological sciences differ from most of the natural sciences is that their study objects have been constructed by humans, rather than being objects from nature. This is of course a very basic difference, but two reservations need to be made so that it is not applied too simplistically.

First, this difference refers to the ultimate study objects of the respective disciplines. Natural scientists often study objects that have been modified for the purpose of measurement or experiment, but this is done only as a means to better understand objects or phenomena that occur naturally. As one example of this, in order to determine the structure of a protein it is often useful to produce a crystallized form of it. The investigation then takes place on the crystallized protein, that is not a naturally occurring object but has been modified by humans. However, for the biochemist the crystallized protein is not the ultimate study object. It is studied in order to understand the structure and the workings of the naturally occurring protein. In contrast, the human constructions studied by technological scientists, such as machine parts and computer programs, are their ultimate study objects.

Secondly, one of the natural sciences, namely chemistry, is similar to the technological sciences with respect to its study objects. Most of the substances studied by chemists are not known to occur in nature.

4.2.2 Design is included

The design of new technological objects is an essential component of engineering. It is also an important part of the work of many academics in the technological sciences. Technological scientists do not only study human-made objects, they also construct them.

Just as in the previous subsection, a caveat concerning chemistry is needed: Synthetic chemistry is similar to the technological sciences in that it aims at the construction of new objects (in this case, new chemical substances). (Schummer, 1997) There is, however, an important difference between chemical synthesis and engineering design. Chemical synthesis is aimed at obtaining a substance with a specific, predetermined molecular structure. In contrast, engineers designing a new product work with a complex and often not fully explicit list of design specifications or goals. The ideal outcome of the design process would be a product that fully satisfies all the design goals. In practice, however, such an outcome is seldom achieved. Compromises and trade-offs between conflicting design criteria have to be made in the course of the design process. (Asimov, 1974. Vincenti, 1990. Vincenti, 1992.)

Engineering design has an important role in the development of new experiments in the natural sciences. It is common for new experiments to depend crucially on the design and production of new experimental equipment. From this point of view, the natural sciences are in part based on the technological sciences, just as the technological sciences are in part based on the natural sciences. (Janich, 1978. Kroes, 1989. Lelas, 1993.)

4.3 Basic concepts

The conceptual resources of the technological sciences include large parts of the terminology of the natural sciences. In addition, two major classes of concepts are characteristic of the technological sciences, namely functional and normative concepts.

4.3.1 Functional concepts

Some categories of technological artefacts, primarily raw materials and some multi-purpose components, are defined according to their physical properties (steel girder, copper wire, plank). In order to determine whether or not an object belongs to one of these categories we have to find out its physical characteristics such as its form and its material composition. However, the vast majority of the categories that we use to classify technological objects are specified according to functional rather than physical characteristics. Hence, in order to determine whether or not an object is a screwdriver we have to determine whether or not it has the function of driving screws. Therefore, screwdrivers are a functional category. The same applies to object categories from all parts of the vast "universe of devices" that we humans have constructed. Saws and diodes, ladders and lamps, refrigerators and particle accelerators are all functionally defined categories. The functions that define these and other classes of technical objects serve as conceptual bridges between human intentions and the physical world. (Kroes and Meijers, 2002. Hansson, 2002. Hansson, 2006a. Vermaas and

Houkes, 2006. Kroes, 2006,)

For some types of technological artefacts the criteria of functionality can be very complex. It is no easy task to make a full list of our functional requirements on a car. Arguably this is even an impossible task, since the list is unfinished and always open to additions due to technological or social developments. Our appraisal of a new car model may very well be influenced by features or properties that we had never before thought of in association with motor vehicles.

There is one of the natural sciences, namely biology, in which functions have a central terminological role. Concepts such as fin, eye, gland, stem, flower, and food are all defined according to functions for the organism. The major difference is of course that whereas technological functions have been intentionally assigned to objects, biological functions are our way to describe the outcomes of evolutionary processes. Previous philosophical analyses of function have mostly been devoted to the biological uses of the notion of function, but a good case can be made that this is not the primary usage of functional concepts. It would seem reasonable to assume that the usage of functional concepts to describe undesigned objects (as in biology) derives from how we refer to the functions of designed artifacts.

4.3.2 Normative concepts

Most of the concepts used in the natural sciences are about as free from values and norms as an empirical concept can be. In contrast, the technological sciences operate in a value-laded context that strongly influences their conceptual apparatus. (Layton, 1988) Concepts abound that have a clear value component, such as "user friendly", "environmental friendly", "risk", "safety", and "disaster". We have explicit technological norms in the form of written codes and standards that provide us with detailed specifications for a wide variety of technological products, practices, and procedures. Most importantly, evaluations of technological objects have a central role in technological science and research. We perform research in order to construct better bridges, cars, computers, computer programs, medical implants, etc. In terms of the role of values, technological sciences are closer to the social than the natural sciences, since the former operate with value-laden concepts such as "justice", "welfare" etc.

There is a characteristic form of value statement that is common in the technological sciences, namely category-specified statements about technological objects. A category-specified value statement is one in which a value judgment is specified in relation to the standard that is associated with some category that the object of value belongs to. (Hansson, 2006b) Hence, if we say that a person is a "good driver", we do not assign value to this person in general but (only) to her as a driver.

As was mentioned above, functional categories tend to dominate in most areas of technological discourse. Consequently, most category-specified value statements made in technological contexts refer to a functional category. In other words, the value-specifying category (such as "screwdriver" in "this is a good screwdriver") consists of objects that have a certain function in common. The meaning of the value statement is often relatively clear from the functional description. Hence, a hammer is an object with the function of driving nails or striking blows at material objects. It follows from this that a good hammer is one that satisfies this function well, so that blows can be struck with maximal precision and minimal effort. In general, if we know functionally what an X is, then we also know what a good X or a bad X is.

Category-specified values statements can also refer to objects that are defined according to their physical properties rather than their functions. Hence a "good" steel wire is one that has the properties needed in most applications in which steel wires are used. More generally speaking, technological objects that are not defined in terms of functions are nevertheless evaluated in terms of the functions for which they are typically used. As this shows, the technological sciences share with practical engineering a well-developed system of value judgments that distinguishes them from other areas of science.

4.4 Theoretical models

The technological sciences operate with models, theories, and hypotheses in much the same way as the natural sciences. However, there are two distinguishing characteristics of the models used in technological science that derive from their specific tasks and purposes.

4.4.1 Less far-reaching idealizations

In science that aims at explaining the underlying workings of the natural world, far-reaching idealizations are made in order to investigate natural phenomena in isolation from each other. (McMullin, 1985.) Hence a physicist who studies electromagnetism uses models of electromagnetic phenomena in which gravitation is absent. Often experiments are performed under specially constructed conditions that are tailored to suit such simplified models. Hence, physical experiments are often performed in vacuum in order to correspond to theoretical models in which the impact of atmospheric pressure has been excluded. Chemical experiments are performed in gas phase in order to ensure that each pair of reacting molecules has no interaction with other molecules. This brings these experiments in closer correspondence to theoretical models of reaction mechanisms.

This all works well in the natural sciences, but it does not work for engineering. The physicist can use a theory of electromagnetism that does not take gravitation into account, but the engineer who builds a machine based on electromagnetic principles cannot disregard the effects of gravitation unless the machine is intended for use in outer space. Similarly, theoretical mechanics does not need to take weather conditions into account. However, in the construction of a suspension bridge the same idealization can lead to a construction that does not resist severe storms, and therefore to disaster. (Layman, 1989)

In summary, some of the idealizations that are useful in the natural sciences have to be dispensed with in investigations of technological constructions. Therefore, more complex models are often needed in the technological than in the natural sciences.

4.4.2 The requirements of mathematical precision

Mathematical problem-solving is an essential part of both the natural and the technological sciences. In both areas there are problems that only require a rough approximative solution, but there are also problems in both areas that require solutions with a high degree of mathematical precision. Hence, if precision is measured in terms of the required number of decimal places, then there does not seem to be any systematic difference between the technological and the natural sciences in the degree of mathematical precision.

There is, however, an important difference in the very nature of the precision requirement. The precision that the engineer needs is always obtainable by means of a sufficiently good approximation. Hence, if the choice of wire dimensions for a suspension bridge depends on the solution of a complex system of equations, the engineer does not need an analytical solution of the system; if a solution has been obtained with a sufficient number of decimals the problem has been solved. In this she differs for instance from an astrophysicist or a population geneticist who needs to solve an equally complex system of equations. For the purposes of the natural sciences, an analytical solution is always preferred (although there are areas, such as quantum chemistry, in which it is seldom obtainable). This may partly be a matter of the aesthetic qualities of the solutions, but it is also a matter of their explanatory qualities. There is a good chance that the insights obtainable from an exact solution can contribute to the solution of other similar problems in the future.

4.5 Conclusion

In summary, the technological sciences have at least six defining characteristics that distinguish them from the natural sciences. The technological sciences

have human-made rather than natural objects as their (ultimate) study objects

include the practice of engineering design

define their study objects in functional terms,

evaluate their study objects with category-specified value judgments

employ less far-reaching idealizations than the natural sciences

do not need an exact mathematical solution when a sufficiently close approximation is available

The first of these characteristics is in part shared with chemistry and the third with biology. However, in combination the six characteristics are sufficient to show that the technological sciences are neither branches nor applications of natural sciences, but should be distinguished as a different group of sciences.

5 Technological function

5.1 Function as a classificatory principle for technology

From Sven Ove Hansson "Values in Chemistry and Engineering", pp. 235-248 in Peter Kroes and Peter-Paul Verbeek, The Moral Status of Technical Artefacts, Springer 2014.

Technological objects can be described either in terms of their physicalstructural characteristics or in terms of their functions (wooden cylinder, 3 mm thick and 94 mm in diameter cup coaster). According to the dual nature theory of tech-nological artefacts, they can be understood both as physical objects and as objects with certain functions. Whereas the physical properties of a technological object can be described without any reference to human intentions, its functional proper-ties are closely related to the intentionality of design processes (Kroes and Meijers 2006. Kroes 2006. Vermaas and Houkes 2006. Hansson 2006b).

Some of the categories that we use to categorize technological objects are pure-ly functional. Nutcrackers, calculators, pens, airplanes, and CPUs are examples of this. A device with the function to crack a nut can be called a nutcracker, irrespectively of its physical structure. The defining characteristic of a purely functional category is that in order to determine whether an object belongs to that category it is sufficient to ascertain its function. Hence, in order to determine whether an ob-ject is a plough we have to find out whether or not its function is to turn over the upper layer of the soil. In order to determine whether a computer program is a search machine we have to find out if it serves to find digitally stored information. We do not need to find out what its components are or how they have been combined.

Other technological categories are predominantly structural. This applies for instance to the notions of a plank, a steel wire, a rope, and a fibreboard. As these examples indicate, technological categories defined in structural terms tend to be raw materials or multi-purpose components. The defining characteristic of a structural category is that in order to determine if an object belongs to it, it is sufficient to know its structure, i.e. what its components are and how they are put together (however, as was pointed out to me by Peter Kroes, when we describe an object in purely structural or physical terms we are, strictly speaking, referring to it as a physical rather than a technological object).

There is also a third type of categories of technological objects, namely those whose definition combines functional and structural characteristics. The notion of scissors is an example of this. Saws, knives, and scissors have very similar functions; to distinguish them we need to refer to their structural properties. We call a cutting instrument a pair of scissors only if it has two edges that can slide against each other; furthermore its cutting function must rely on that sliding of edges. Cogwheels are another category of the mixed type. We would not use that term for a toothed wheel that was constructed for some other purpose than to connect it with another toothed device so that movement of one of them induces movement of the other. Neither would we use it for an untoothed wheel that connects with another wheel through some other mechanism. The defining characteristic of this mixed type of categories of technological objects is that in order to determine whether an object belongs to such a category it is necessary to have information about both its structure and its function.

The categorization of technological objects can often be performed in several steps, in categories and subcategories. In the creation of subcategories, structural or functional categories are often subdivided into subcategories of the mixed type. Hence "engine" is a functional category but "two stroke engine" a mixed one. "Clock" is a functional category but "pendulum clock" a mixed one. "Plank" can be defined as a structural category ("a piece of sawn timber at least 50 mm thick and 225 mm wide" according to the Oxford English Dictionary), but "floor plank" is certainly a mixed one. Some categories can be divided into subcategories both in terms of structure and function ("pipe" "copper pipe" "sewage pipe"). In summary, engineers operate with terminologies that are based on complex mix-tures of functional and structural specifications. In this respect, the "dual natures" of technological objects are intertwined rather than juxtaposed.

5.2 Several kinds of function

(From Sven Ove Hansson, "A milestone in the philosophy of technology". Techne 17(3):368-373, 2013.

A distinction must be drawn between an objects function and its functional kind. As a very rough first approximation, many technical artefact kinds seem to be definable in terms their typical functions. For instance, a candlestick is a device that holds a candle in a position in which it can be burnt, so why not just define candlestick as an object with that function? For at least two reasons, this simple format for defining functional kinds does not work.

First, not all assignments of functions have the power of making their object a member of the corresponding functional kind. I may have kept burning candles in the same old wine bottle for a decade or more, but it is still a bottle, not a candlestick. To explain this Peter Kroes has introduced what may be called the prerogative of the designer: The designer determines the kind-proper function of an object. This is the function that defines what technical artefact kind the object belongs to, something that cannot be changed by later function ascriptions for instance by owners or users of the object. As a user you can decide the objects “use-proper functio”, for instance by deciding to use a specific wine bottle for holding candles or (as is common among burglars) to use a specific screwdriver as a window opener. Such decisions are different from the temporary (“accidental”) use of the bottle or the screwdriver on a single occasion for the respective purpose, but they still do not make the object member of another technical artefact kind than that determined by its designer.

Kroes expresses this as a distinction between an object that is for ψ-ing and an object that is a ψ-er. As a user I can make a specific pair of tongue-and-groove pliers into an object “for nut-cracking” but I cannot make it “a nutcracker” because I cannot revoke the (kind-proper) function ascription of its designer.

Secondly we need to account for the status of objects that do not match up to their function ascriptions. This is most clearly illustrated with malfunctioning objects. The CD player in my living-room cannot be used to play records any more and will have to be replaced. However, it is still a CD player. Generally speaking, malfunctioning technical artefacts do not lose their membership in technical artefact kinds.

These distinctions are summarized in Figure 5 where a simple Venn diagram summarizes the relationships among the three categories of ascribed function (X is for ψ-ing), functional kind (X is an ψ-er), and functionality (X can be used for ψ-ing). Each point in the diagram represents the combination of some concrete object and a function. Field 5 represents the central case of a successfully designed object that is used for its intended purpose, such as my wristwatch in relation to the function of showing the time of the day. Field 4 represents the case illustrated by the wine bottle to which I have assigned the role of a candlestick: this object has the function of holding candles but it does not belong to the corresponding functional kind of candlesticks. My broken CD player illustrates the type of objects we find in field 2. (The same field also contains objects belonging to technical artefact kinds that refer to unrealizable functions such as “perpetuum mobile” and “homeopathic remedy”.) The old coat that a farmer used as a scarecrow and the crows as a sitting-place belongs in field 1; it has been assigned the function of scaring off birds but it was not designed for that purpose and neither does it fulfil it. In field 7 we find for instance my best woodworking chisel in relation to the function of opening paint cans.

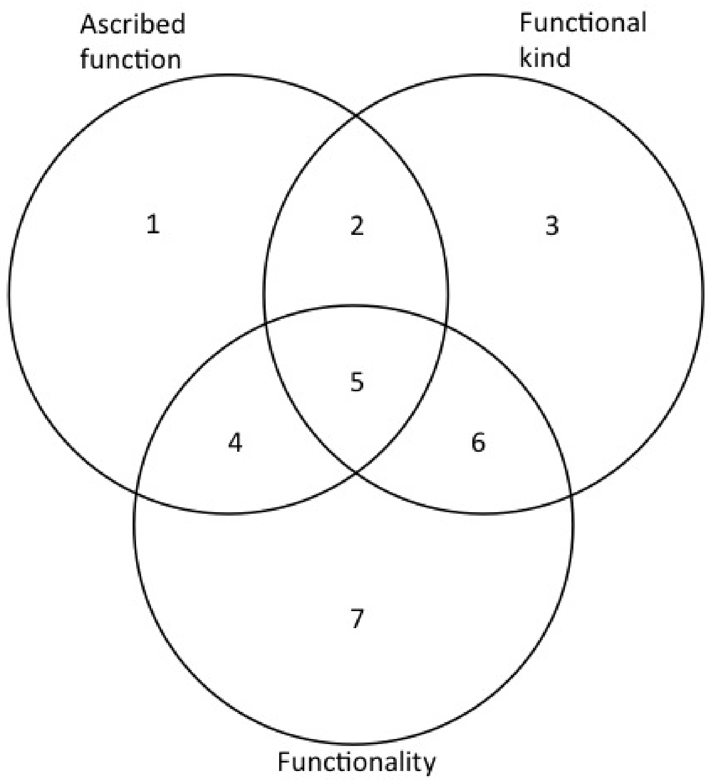

Figure 5: Figure 5. The relationships among ascribed function, functional kind, and functionality.

Fields 3 and 6 are more problematic. Possibly these two fields should be empty. However there are limiting cases when this is less clear. Modern suppliers of plate armours and swords do not necessarily imply that the products they sell actually serve the functions indicated by their names. An object may be classified by its designer as a sword without being assigned (by the designer or anyone else) the function that a sword is normally assumed to have. But admittedly, the cases that suit into fields 3 and 6 seem to be so marginal that it may reasonable to treat these fields as empty.

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