THE NATURE OF TECHNOLOGICAL KNOWLEDGE

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1 FROM APPLIED SCIENCE TO EPISTEMIC EMANCIPATION

Two decades ago, John Staudenmaier took stock of twenty-five years of research published in *Technology & Culture*, a leading journal for historians of technology. He identified three key debates, one of which is the relation between science and technology. This debate was largely shaped by the "technology-is-applied-science" thesis, often attributed to Mario Bunge [1966], and the objections to this thesis. Staudenmeier ends his overview of the debate with an intriguing conjecture, worth quoting in full:

> Thus, it would appear that a substantial number of [historians who published in *Technology & Culture*] interpret technological praxis as a *form* of knowledge rather than as an *application* of knowledge.
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> By their discussions of scientific concepts, problematic data, engineering theory, and technical skill, the authors have begun to develop a complex and provocative model. If these discussions are, in fact, the beginning of a new theme in [*Technology & Culture*], we may find that the more limited science-technology question will take its place as a subtheme within the more inclusive model. [Staudenmeier, 1986, p. 120]

Twenty years later, the antecedent of the last statement has proved false. Staudenmeier's conjecture about the start of a new theme, around say 1980, can be supplemented with a statement about the development of this theme after 1986: neither in *Technology & Culture*, nor elsewhere has this "more inclusive model" been developed. What is worse, after the publication of Walter Vincenti's *What Engineers Know and How They Know It* [1990], research concerning the nature of technological knowledge seems to have come to a standstill.

Historians of technology have lost interest in the topic. One illustration is Samuel Florman's [1992] review of Vincenti's book in *Technology & Culture.* In the review, Florman complains about Vincenti's excessive interest in epistemological details at the price of attention to people and organizational issues. Philosophers have not rushed in to fill the gap left by historians. Technological knowledge is

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not even a minor theme in journals that cover epistemological and methodological issues. The handful of papers that have been published on the topic reverse Staudenmaier's prediction: they typically address the science-technology relation and treat the nature of technological knowledge as a side issue. Furthermore, all papers are isolated efforts, and often repeat points that have made in the technology-as-applied-science debate before the 1980s. There is no philosophical research tradition regarding technological knowledge, in which authors build upon, or even respond to each other's work. Even individuals have seldom published more than a few papers on the topic, meaning that there are not even personal research traditions.

It cannot be concluded from twenty years of disinterest in technological knowledge that the subject is not interesting. It may, perhaps temporarily, have gone out of fashion among historians and philosophers. The situation does, however, pose an interesting challenge for an overview of the work on technological knowledge.

Therefore, in this paper, I review several different, occasionally quite slender bodies of literature to find out whether there are possibilities to revive the interest in technological knowledge. In particular, I consider to what extent the scattered, divergent research on technological knowledge — organized into several themes in this overview — supports a strong, and therefore interesting epistemological claim made at the start of the Staudenmaier quote: that technological praxis may be interpreted as a *form* of knowledge. This claim is not unique to Staudenmaier. Take, for instance, George Wise's summary of historical findings as:

> Treating science and technology as *separate spheres of knowledge*, both man-made, appears to fit the historical record better than treating science as revealed knowledge and technology as a collection of artifacts once constructed by trial and error but now constructed by applying science. [Wise, 1985, p. 244; emphasis added]

Vincenti approvingly quotes Wise and several other researchers, including Barnes and Layton, as concluding that "technology appears, not as derivative from science, but as *an autonomous body of knowledge*, identifiably different from the scientific knowledge with which it interacts." [1990, pp.1-2; emphasis added]. Layton in turn seems to derive this view from the work of Alexandre Koyré, writing that

> [Koyré] held that technology constituted a system of thought essentially different from that of science. Technology generated its own independent rules which came ultimately to constitute a body of technological theory. [Layton, 1974, p. 40]

These quotes show two things that are useful for an overview. Firstly, they express an aim that shapes several existing studies of technological knowledge. This aim may be called the *epistemic emancipation* of technology, i.e., to establish that technology is epistemically distinct from science. This emancipation aim makes sense against the background of the technology-as-applied-science debate in the 1960s and 1970s. In the last half of the 1980s, denying that technology merely involves the application of scientific knowledge was no longer in need of further argumentation. Thus, a next step could be considered: that technology involves its own form of knowledge.

However — this is the second useful aspect of the quotes — the epistemic-emancipation claim can be interpreted in various ways. In one sense, which I call "weak emancipation", it says that scientific and technological practice result in bodies of knowledge that are as distinct as our knowledge of plants and animals, or perhaps more strongly, as distinct as physics and chemistry. "Distinct" here means no more than that there is, as yet, no way of incorporating one body of knowledge into the other.

One might think that this is a defensible, and sufficiently emancipatory claim about the relation between scientific and technological knowledge. Yet many authors might also be interpreted as making a stronger claim. Calling our knowledge of plants and animals "separate spheres", "autonomous bodies", or "of different forms" sounds exaggerated: irreducibility does not entail separation, let alone autonomy. If autonomy is taken in its standard sense of "self-government", or the ability to set one's own rules, it leads to a far stronger emancipatory claim than the minimal one considered above. Technological praxis results in an *autonomous* body of knowledge if this knowledge answers to its own epistemic rules, not those of science. Physics and chemistry are not mutually autonomous in this sense, since they answer to approximately the same rules; justifying a claim in physics is not qualitatively different from justifying a claim in chemistry, although specific methods may of course differ. Thus, calling technological knowledge "autonomous" more strongly emancipates it from scientific knowledge. Given the applied-science debate, this strong emancipation seems attractive. Having denied the thesis that technological praxis is epistemically dependent on science, one might be eager to prove that technology is epistemologically self-supporting, and not necessarily related to science.

Reviewing the existing literature on technological knowledge shows that the strong autonomy thesis plays an important role in it. But this does not mean that authors have tried to validate the thesis in exactly the same way, nor that they have successfully established it. In this chapter, I give a critical overview of the literature by distinguishing four emancipation strategies that have been developed — without claiming that every author pursues only a single strategy, or that authors have appreciated the differences between the various strategies. These strategies are:

- to contrast directly scientific and technological knowledge (Section 2).
- to construct a taxonomy of technological knowledge (Section 4).
- to appeal to the "tacit" nature of technological knowledge (Section 6).
- to appeal to the prescriptive nature of technological knowledge (Section 8).

After showing how the strategy has been endorsed, expressed and developed, I critically analyze its current success in establishing strong emancipationism.[1] Furthermore, most review sections are succeeded by a section that contains a more general argument against the effectiveness of the strategy.

To anticipate my conclusion: although the literature on technological knowledge is significantly shaped by the strong-emancipation ideal, efforts to realize it have not only been scattered and idiosyncratic, but also significantly underestimate the difficulties in establishing the ideal. My arguments do not show that strong emancipation is impossible to defend, but they do show that current arguments are ineffective.

The critical review is complemented by a short look at one reason why historians and philosophers of technology might have abandoned Staudenmaier's epistemic theme and the emancipation quest (Section 9). Still, I end the chapter on a more constructive note. In the course of my critical analysis I identify less ambitious and more detailed issues that might be addressed to improve our understanding of technological knowledge. I conclude with offering some suggestions for reviving the study into the nature of technological knowledge (Section 10).

2 CONTRASTING NATURAL AND ENGINEERING SCIENCE

A popular strategy for studying technological knowledge and arguing for epistemic emancipation is to contrast science and technology — more specifically: to look at differences between natural and engineering science. The latter is certainly not equivalent to technology, but I shall show that the narrowing of scope is understandable. Here, I review existing developments of the contrastive strategy.

A first thing to note is that most authors who develop this strategy also share a key intuition. This intuition — which is not exclusive to the contrastive strategy — is that technology is, in all its aspects, aimed at practical usefulness. Thus, whether technological knowledge concerns artefacts, processes or other items, whether it is produced by engineers, less socially distinguished designers, or by consumers, the *prima facie* reason to call such knowledge 'technological' lies in its relation to human goals and actions. And just as scientific knowledge is aimed at, or more tenuously related to, the truth, so technological knowledge is shaped by its relation to practical usefulness.

This 'truth vs. usefulness' intuition — TU-intuition for short — is repeated, in slightly different wordings, in many works, especially those in which a rough-and-ready characterisation of technology or technological knowledge is sought. Take, for instance:

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[1] Neither the weak nor the strong emancipation ideal is made explicit in the literature on technological knowledge. Some of the work reviewed in this essay might be interpreted as arguing for weak, rather than strong emancipation. Given my critical analysis, this interpretation might be more charitable. It is also less interesting, since establishing weak emancipation is a rather trivial aim. Thus, I have taken the liberty of reviewing/reconstructing the literature with regard to its effectiveness in achieving a more difficult, perhaps even unattainable, goal.

> Technology… aims to be effective rather than true [Jarvie, 1972, p. 55]
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> Science seeks basic understanding (…). Technology seeks means for making and doing things. [Hindle, 1966, p. 4]
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> Science concerns itself with what is, technology with what is to be. [Skolimowski, 1972, p. 44]

The TU-intuition also shapes Walter Vincenti's work. From virtually all his individual case studies, Vincenti draws the conclusion that technological knowledge is distinct from science because it is related to practical purposes. One telling quote is the following:[2]

> [T]he criterion for retaining a variation in engineering must be, in the end, *Does it help in designing something that works in solution of some practical problem?* The criterion for scientific knowledge, however we put it, must certainly be different … Borrowing a phrase used by Alexander Keller … I would venture it more or less as follows: *Does it help in understanding 'some peculiar features of the universe'?* [Vincenti, 1990, p. 254]; (original emphasis)

Few authors go beyond expressing the TU-intuition and arguing why it shows that technology involves more than applying scientific knowledge. This is unfortunate, because the intuition alone does not at all establish epistemic emancipation of any variety. For the intuition does not only present a questionable image of science (an objection that shall be considered in Section 3), but it is also unclear on the technology side: does it address engineering practice, engineering science, engineering design and/or technology in one of the possible senses of the term? These meanings can be distinguished more or less clearly (see e.g., [Mitcham, 1978]), and it is often useful to do so. However, a focus on epistemological issues might make the distinctions less relevant. The reason is that not all technological practices are, on the face of it, equally relevant to technological knowledge. Engineering practice, design, and also the use of technical artefacts typically involve knowledge, and might often lead to acquiring knowledge, but they are not primarily knowledge-producing activities. Engineering science is. Therefore, it is a natural starting point for inquiries into the nature of technological knowledge.[3]

Those who go beyond expressing the TU-intuition frequently focus on the engineering sciences and the role of theories and models in these disciplines. The common supposition is that this role is instrumental. More than natural scientists,

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[2] Passages in which Vincenti expresses the TU-intuition in slightly different, artefact-oriented words, are: "In scientific knowledge the purpose is understanding of nature; in engineering science the ultimate goal … is the creation of artefacts"[Vincenti, 1990, p. 135] and "Engineers use knowledge primarily to design, produce and operate artefacts, goals that can be taken to define engineering. (…) Scientists, by contrast, use knowledge primarily to generate more knowledge" [*ibid.*, p. 226].

[3] Engineering science is also a risky starting point, because of all technological practices, it is probably closest to science, and therefore least likely to be autonomous — or even in need of autonomy.

engineering scientists are supposed to be content with theories and models that are practically useful, but known to be incorrect. This way of studying technological knowledge is not only evidently connected to the TU-intuition. It also stands a good chance of non-trivially developing it, because it generates some specific research questions — which test both the TU-intuition and the ideal of strong emancipation. I give only two examples of such questions here, in the form of specific hypotheses.

Firstly, if practical usefulness is the central value of technological practice, one would expect this to affect the validation of theories and models in engineering science, given their obvious relation to technological practice. To put it roughly, one would expect theories and models in engineering science to be valued if — although perhaps not *only* if — they are usefulness-tracking, unlike theories and models in natural science. If this abstract difference, based on the TU-intuition, is not manifested in concrete evaluations of theories and models, it makes little sense to call technology epistemically autonomous, at least in this important respect.

Secondly, engineers frequently employ theories from the natural sciences. If we suppose that these theories were previously evaluated for their verisimilitude and that engineering scientists value them for their usefulness, one would expect that changes (if any) to these scientific theories and models reflect this shift of values — and that not all such changes are valuable within the natural sciences. If no such changes are made, or if every change by engineering scientists is hailed as simultaneously advancing scientific research, the distinction between scientific and technological knowledge has no normative bite.

Neither these nor other, equally specific hypotheses regarding technological knowledge have been investigated. Most authors who address epistemic differences between science and technology are content to state the TU-intuition, giving some illustrations — usually of artefacts that were developed on the basis of false theories or in the absence of theories. The validation of theories and models used in the engineering sciences is seldom studied. Still, some papers identify or even illuminate the issues raised above. I discuss four in some detail.

The first three papers address the first issue, that of the validation of theories and models developed within the engineering sciences. Both Ronald Laymon [1989] and Vincent Hendricks, Arne Jakobsen and Stig Andur Pedersen [2000] relate the development of specific models to the central value of practical usefulness. Their main aim is to show *that* this value is at work and that engineering is therefore different from science, but they also offer material for the more valuable analysis of *how* the value affects the evaluation of models.

Ronald Laymon examines the role of as-if theories, or fictitious models in engineering science. More specifically, he studies the history of models of a swinging pendulum, as they might be used in instrument building. Such models have to account for buoyancy effects: the textbook harmonic-oscillator idealization is of little use for practical purposes. One way to provide such an account is to correct for the mass of displaced air, and then to correct this by means of an experimentally determined correction factor — which accounts for all non-hydrostatic effects of the presence of air. Such empirical data raise a projectibility issue: will they apply to slightly different pendulums in slightly different circumstances? Laymon discusses various responses to this question that may be typical for engineering. One is that, in technological practice, the projectibility issue may be largely avoided by rebuilding successful devices and/or (artificially) recreating the circumstances of successful performance. This does not add significantly to the body of technological knowledge, making this response uninteresting for our current purpose. Another response is more interesting. To understand the behaviour of pendulums in new circumstances, the experimental correction factors may be analysed for continuities and correlated changes, and one may seek explanations of such correlations. The engineering scientist appears to have considerable freedom in seeking explanations: because of the ultimate goal to produce practically useful artefacts, clearly fictitious or as-if theories are just as welcome as realistic ones. Laymon mentions Airy's theory of "adhesive air" as an example: the presence of air may be accounted for by supposing that a quantity of air adheres to the pendulum while moving — adding to its buoyancy without changing its weight. This theory can be taken seriously within engineering science if it has instrumental value. Moreover, it leaves open a more realistic explanation in terms of the viscosity of air, which can again be corrected for its "viscosity bias".

This cycle of idealized model, correction, explanation and refinement of the model is probably familiar from other experimental sciences. Yet the role that as-if theories play in the cycle presented by Laymon may be characteristic for the engineering sciences.[4] And, what is more important to the topic of this paper, by means of his concrete example, Laymon gives considerably more content to the claim that engineers do not seek "true" theories, and are primarily interested in "usefulness".

Another methodological feature of engineering science, the existence of "lumped-parameter models", is examined in some detail in [Hendricks *et al.*, 2000]. In these models, the behaviour of a system is described by analyzing it as a complex of subsystems, for which idealized models are available. These models may not be realistic. They may even be transferred from a different domain altogether. A mechanical system may, for instance, be modelled in such a way that an isomorphism with the model of an electrical system is revealed. The point of this method of decomposition-cum-isomorphism cannot be veracity. Thus, lumping is another example of the way in which the central value of practical usefulness affects the evaluation of models: because engineering science aims at usefulness rather than truth, (more) lumped-parameter models may be acceptable. This reveals an evaluative difference between the natural and engineering sciences, albeit one that calls for more detailed analysis: as Hendricks, Jakobsen and Pedersen notice, lumping-

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[4] Laymon's expression of this difference relies on the TU-intuition: "The problem created by the use of idealizations for science ... is to determine whether failures to achieve experimental fit to within experimental error are due to the falsity of the theory or of idealization. (...) For the engineer the problem seems altogether different. If [the closeness of predictive fit achieved by theory and idealization] is good enough for some practical purpose then the engineer's job is done ..." [Laymon, 1989, p. 354].

parameter models are also found in some parts of physics. They mention models in solid-state physics; the liquid-drop model of nuclear physics may provide another example. A closer comparative study of the roles these models play, and the conditions for accepting or rejecting them may lead to more insight in the relation between usefulness and the engineering sciences. The liquid-drop model of nuclear physics is, for example, not regarded as *merely* a predictive instrument: it is commonly supposed that nuclei are structurally similar to drops of liquid, and that this explains some aspects of their behaviour. Presumably, engineers do not take the successes of an "electrical" model of a mechanical system to show such a structural similarity. Whether this means that lumped-parameter models in engineering sciences are less tightly constrained, because there are no requirements of truth-likeness, remains to be seen.[5]

Peter Kroes [1992] takes another perspective on the development of theories in the engineering sciences. Rather than stressing the role of idealized or fictional models, he studies what he calls "engineering theories", i.e., formally or mathematically structured, experimentally validated systems of knowledge that explain the technological function of a particular class of technical artefacts or technical-artefact-related materials in terms of their design or construction.[6] Using Pambour's theory of the steam engine as an illustration, Kroes argues that design considerations confer a "distinctly technological flavour" [1992, p. 70] on engineering theories. This flavour shows in three features. Firstly, as the characterization already makes clear, the domain of application of an engineering theory is a designable technical artefact or artefact-related material, not a physical phenomenon: Pambour's theory is about piston-operated steam engines, not about all heat engines. Secondly, engineering theories may contain basic principles related to the design or construction of technical artefacts. These principles, such as Pambour's principle of the conservation of steam, may be reformulated in terms of physical boundary conditions, but they involve more than an application of physical principles: design considerations, not physical considerations, explain why these conditions are relevant. Thirdly and finally, engineering theories employ technical concepts as well as physical ones. Technical concepts are again related to design characteristics. To confuse matters, some theoretical concepts may be homonyms, referring to either technical or physical characteristics. Examples of concepts with such "dual significance" [Kroes, 1992, p. 91] are "resistance" and "pressure".

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[5] Hendricks and his co-authors regard engineering science as combining the values of truthfulness and usefulness: "(...) the objective for engineering science is an optimal degree of theoretical correctness (typically limited by time and resources) combined with pragmatic considerations of practical usability." [Hendricks *et al.*, 1999, p. 302]. This combination view seems to minimize the difference between natural and engineering science, since the former also seems to combine truthfulness and usefulness. See also section 3.

[6] Kroes [1992, p. 69] grafts this characterization on Staudenmaier's [1985, p. 107] definition of an engineering theory. He modifies it to focus on *technical* artefacts, and technological functions rather than behavioural characteristics; both modifications are indeed called for, since: (a) many theories in the experimental sciences describe artefacts, viz. artifically induced phenomena; (b) the behaviour of artefacts can be described in physical or chemical terms.

Of the three papers discussed, Kroes's is the most specific. It focuses on a clearly circumscribed subset of the total body of engineering knowledge, and identifies several distinguishing features. Moreover, it relates these features to some of the most basic concepts used to describe technology, "artefact", "(technical) function" and "design". As I shall argue in the next section, this gives the approach an analytic edge over that in the other two papers, which discuss more general features of engineering models, and appeal merely to the TU-intuition to distinguish the models from scientific ones. Yet Kroes's approach also has drawbacks, partly because of its specificity. For one thing, Kroes's approach might only emancipate a very small part of technological knowledge. Some knowledge may have a "distinctly technological flavour" without being related to a specific type of technical artefact; Vincenti's control-volume analysis, discussed immediately below, comes to mind as an example. Secondly, the basic concepts invoked by Kroes, such as "design" and "function", are in need of further analysis. If, for instance, "design" may refer to the selection of physical objects for practical purposes, and function to physical behaviour, the distinction between engineering theories and scientific theories may evaporate. Thirdly, Kroes's focus on distinctions between concepts is innovative and initially plausible, but at further inspection problematic. If, for instance, "pressure" indeed has a dual significance, should Pambour's theory be disambiguated so that it only contains design parameters? Doing so seems necessary to argue that engineering theories differ from scientific theories "in substance", as Kroes suggests [1992, p. 93]. However, once disambiguated in this way, it is not clear how engineering theories "exploit scientific theories in solving technical problems" [Kroes, 1992, p. 92], since their content is, strictly speaking, different from that of scientific theories.

The second issue, the adoption and adaptation of scientific theories within engineering science, is even more rarely addressed. It is, however, the topic of one of Vincenti's case studies [1990, Ch.4; the original paper is from 1982]. Vincenti examines the development of control-volume analysis, a technique for solving problems regarding fluid flow by selecting a hypothetical surface and calculating the values of physical quantities on its boundaries. This technique is compatible with thermodynamics and does not add irreducible concepts to it, and it is a standard part of many engineering curricula. It is not, however, found in thermodynamics textbooks for physicists — Vincenti mentions a textbook that presented control-volume analysis in an edition for physicists and engineering students, but omitted it in a later edition for physicists alone. The reason is that the technique is global. Control-volume analysis only yields overall results regarding the behaviour of a system; the inside of the hypothetical control volume may be regarded as a physical black box.[7] Within the confines of this black-boxing, control-volume analysis is a powerful technique, which can be used to describe the behaviour of all kinds of devices that involve fluid flow — including rocket motors and pipes in installa-

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[7] A physicist might want to use such a global calculation, if she is interested in predicting fluid flow. It would, however, be remarkable if physicists would develop a *systematic technique* for such calculations.

tions. For such systems, the control volume and the relevant quantities are easily determined by the context of use: “what goes in” and “what comes out” are far more relevant to the performance of artefacts than “what goes on inside”. Thus, control-volume analysis shows how engineering scientists adopt a physical theory and make it suitable for their, presumably, different purpose.

From this brief review, it can be concluded that the evaluation of theories and models in engineering science points out several interesting, possibly distinctive features of technological knowledge — but that the literature does little more than point out these features, and that emancipatory arguments often appeal to the TU-intuition without explicating it. Furthermore, all efforts to examine evaluative differences between natural and engineering science have been isolated: the papers reviewed have not given rise to sustained discussion or further refinement; they do not even build upon each other.

3 THE INSTRUMENTALIST OBJECTION

The discussion above has shown that the TU-intuition is a recurrent theme in the literature on technological knowledge. As stated above, the TU-intuition understands the difference between natural science and technology (or, more narrowly, the engineering sciences) in terms of a difference in goals: the former aims at finding out true theories, whereas the latter aims at practical usefulness. In this section, I point out that merely appealing to this intuition is not sufficient to emancipate technological knowledge.

For the difference in goals appears to presuppose a realist conception of science, on which scientific theories ought to be interpreted as descriptions of (the structure of) reality, and science as a continuing enterprise to construct more accurate theories. There are, of course, many ways of developing this realist view of science and scientific theories,[8] and a one-line description may not be representative for all of them. Still, the broad spectrum of realist conceptions can be contrasted with another view of science: instrumentalism.[9] Instrumentalists seek to decouple scientific inquiry from truth, and instead emphasize its connection to usefulness. There are several ways to achieve this. Some instrumentalists argue for a re-appraisal of the notion of truth that is relevant to scientific inquiry: instead of the traditional correspondence theory, they propose a “pragmatic” theory of truth. Other instrumentalists prefer an epistemic route to the semantic one. They accept the realist idea that scientific theories are candidates for being true in a correspondence sense, but they deny that scientists may justifiably accept or reject a theory because of its truth-likeness. Instead, they say that theory choice

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[8] See, for instance, Ladyman’s [2007] review of traditional and contemporary varieties of realism and instrumentalism.

[9] The discussion of instrumentalism as an alternative to scientific realism does not reflect an opinion that instrumentalism is the only viable anti-realist conception of science. Rather, instrumentalism is the anti-realist conception that most directly undermines the TU-intuition.

ought to be dictated by the usefulness of theories for solving the empirical and theoretical problems of science.[10]

That the instrumentalist conception of science conflicts with the TU-intuition is clear enough. If, like technology, science is concerned with usefulness instead of truth (in the correspondence sense), forging an epistemic distinction between the two activities in terms of their goals seems a questionable enterprise. More specifically, the primary epistemic virtues of science and technology would be the same, making it impossible to emancipate technology from science through distinguishing their primary epistemic virtues.

One might try to overcome this obstacle by arguing directly against the instrumentalist conception of science, or at least to decrease its plausibility by attacking the arguments supporting it. Such a maneuver would lead us into the territory of the general philosophy of science, so I do not consider it here. However, its effectiveness seems doubtful. Instrumentalism is a minority position in the philosophy of science, but the arguments used to sustain it, such as the pessimistic induction and underdetermination thesis, are plausible and remain defensible despite numerous attempts to invalidate them. It would be interesting to see whether technology offers a fresh perspective on the entrenched realism debate, but it is hard to feel optimistic about the possibilities of a major breakthrough.[11]

Another response might be to accept the main thrust of the argument, but to remove its sting by arguing that technological knowledge is appraised, not in terms of usefulness in general, but in terms of *practical* usefulness. Technology concerns deliberate changes that serve more or less immediate practical purposes, like transportation and hygiene. To these purposes, engineers primarily produce (designs of) technical artefacts, including systems and processes, and they are aided in this by theories. Scientific theories may be understood as instruments, just like technical artefacts, and the construction of theories may be an instrumental activity, just like design. Yet these instruments serve "theoretical" purposes such as predicting or capturing data, rather than the "practical" purposes that shape technology.

This response might go some way towards dispelling the instrumentalist objection. Yet it appears that, by accepting the gist of the objection, the goal of epistemic emancipation becomes unattainable. If science and technology are subordinate to the same primary epistemic virtue — namely usefulness — establishing strong emancipation by focussing on more specific goals seems difficult. Theories in particle physics and microbiology serve different specific purposes, e.g., to predict the behaviour of mesons and of enzymes, but since the primary epistemic virtue is the same for both types of theories, we might not want to say that they answer to their own sets of rules; instead, physical and microbiological knowledge

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[10] [Stanford, 2005] is a recent overview of historical, current and possible instrumentalist conceptions of science.

[11] One may build upon Hacking's [1983] suggestion that scientists treat those objects as real which they can manipulate, and to examine the role of technology in shaping this manipulability, and of engineering science in describing it.

are typically regarded as species of one epistemic kind, namely scientific knowledge. This worry increases once an additional feature of the response is noticed. No one would want to deny that technical artefacts, such as cars and hand soap, serve immediate practical purposes. But artefacts do not constitute technological *knowledge*, although their design and production might be based on it. It seems that, to keep the strong-emancipation ideal alive, the TU-intuition must be explicated by focussing on the *epistemic* products of technology, such as theories and models in the engineering sciences. At this level, making a principled distinction in terms of specific goals is less plausible. The liquid-drop model is known to be unrealistic, but still used to predict the behaviour of nuclei. Airy's adhesive-air theory is known to be false, but used to predict the behaviour of pendulums. If there are any epistemic differences, they remain to be discovered, below the surface.

This renewed objection suggests a third response, which is to bite the bullet. For the moment, instrumentalism regarding scientific theories seems a viable position, which reduces the epistemic contrast between science and technology to the vanishing point. Therefore, philosophers of technology who seek epistemic emancipation cannot rely on a realist image of science — despite multiple attempts, this image has not been shown to be sufficiently reliable, and the naive version that appears to be presupposed in the TU-intuition certainly needs significant refinement.

Still, detailed studies into the acceptance of theories and models by engineers — such as those discussed in Section 2 — may lead to additional arguments for a realist image of science, or to an instrumentalist image that retains some contrasts with technology. If it could be shown, for instance, that the contexts in which engineers accept unrealistic models are qualitatively different from the contexts in which scientists would be prepared to do so; or that engineers accept more blatantly false theories than any scientists would be prepared to do, then the apparently contrast-reducing statement that "Both scientists and engineers use theories as instruments" could be explicated into different statements about science and technology. Such a sophisticated response has, to the best of my knowledge, never been given. As indicated above, Laymon considers the need for such a response, offers material that may be helpful, but ultimately relies on the TU-intuition and a realist image of science himself.

Alternatively, one could follow Kroes's example and try to specify the instrumental role of engineering theories and models by more closely circumscribing the practical purpose, e.g., in terms of the design and construction of technical artefacts. This strategy seems promising, in the sense that it might explicate the TU-intuition in terms of several concepts that are fundamental to our descriptions of technology. However, these concepts, such as "design" and "technical artefact" are in need of further analysis. Furthermore, narrowing down the practical context of technology runs the risk of narrowing the scope of one's analysis of technological knowledge — as pointed out in Section 2, Kroes's analysis of engineering theories might address only a small portion of what might be called technological knowledge.

Still, by developing arguments and analyses along the lines suggested here, philosophers of technology could examine the role of theories and models in the engineering sciences and simultaneously contribute to the philosophy of science, instead of (perhaps unconsciously) applying insufficiently sophisticated ideas from the philosophy of science.

4 TAXONOMIES OF TECHNOLOGICAL KNOWLEDGE

Inventorizing the contents of technological knowledge would improve our understanding of it. This need not involve an explicit contrast with another type of knowledge, just like an inventory of bears need not involve contrasting them with wolves. Thus, the taxonomical way of analyzing technological knowledge is at least prima facie different from the contrastive analysis outlined in the previous two sections. Yet, like this analysis, making an inventory can serve the purpose of epistemic emancipation:[12] if the items on this inventory are sufficiently different from those on an inventory of scientific knowledge, one may take this as evidence that they embody different types of knowledge.

The traditional distinction between fields within the engineering sciences is an obvious starting-point for a classification of technological knowledge. In engineering schools and elsewhere, e.g., in library cataloguing systems, we find taxa such as mechanical engineering, chemical engineering, and bio-medical engineering. These disciplines and bodies of knowledge appear to be named after the kind of scientific knowledge that they are thought to apply. Moreover, we find taxa such as software engineering and maritime engineering, which appear to be based on the kinds of artefacts produced within the fields. Neither way of classification seems epistemically informative, and the former might even strike those interested in epistemic emancipation as misleading. It is therefore hardly surprising that attempts at classification seldom start from existing distinctions between engineering fields and sciences. They are even seldom presented as attempts at reconstructing or revising these distinctions. Rather, most classifications present categories that cut across the boundaries between fields and disciplines.

Several authors have proposed taxonomies of technological knowledge. I shall give an overview of four efforts: those made by Vincenti [1990], Ropohl [1997], Faulkner [1994], and de Vries [2003].[13] Not all of these authors explicitly state the purpose of epistemic emancipation.[14] Nevertheless, given the context of this

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[12] The taxonomies may serve other purposes, for instance aiding engineers in classifying and storing their knowledge. Broens and De Vries [2003] note that engineers find Vincenti's taxonomy most useful for this purpose — which is compatible with any conclusion regarding the usefulness of this taxonomy for emancipatory purposes.

[13] My presentation in the remainder of this section has profited from Broens and De Vries [2003], but differs from it in some details and criticisms.

[14] The doubts I raise (especially the general doubts presented in Section 5) might strike some as unfair criticisms of proposed taxonomies. One might reasonably doubt whether a taxonomy could even in principle be used for emancipatory purposes, i.e., to determine the (autonomous) nature of the knowledge that is classified. Still, existing work on technological knowledge often

paper, I shall review all four in this light. Moreover, I shall assess the taxonomies with regard to their formal merits: as taxonomies, they ought to present categories that are mutually exclusive and jointly complete; every item in the domain should be classified in one and only one category. In the next section, I go on to consider the viability of the taxonomical way of emancipating technology from science.

The Table (pp. 324–325) provides an overview of the categories of knowledge introduced by the four authors, along with subcategories, a one-phrase clarification, and/or some examples. Not all labels may be self-explanatory; indeed, key notions in all four taxonomies are in need of further analysis. For the moment, I postpone further clarification and comments. In the remainder of this section, I focus on three aspects of the taxonomies: their formal characteristics; their mutual differences; and the way(s) in which they bring to light the relation between technological and scientific knowledge.

Let us start with the formal characteristics, i.e., exclusiveness and completeness. Here, Vincenti's classification performs badly — as he admits before starting his presentation [1990, p. 208]. To give just one example, his scheme is partly guided by the distinction between codifiable theoretical tools and quantitative data on the one hand, and uncodified practical considerations on the other.[15] However, practical considerations may be codified [1990, p. 219], without thereby turning into either tools or data. A similar observation may be made regarding Faulkner's taxonomy, since she incorporates Vincenti's distinction, rephrasing it as one between "practical experience" and "engineering theory". Furthermore, she grounds her distinctions in the possible subjects of technological knowledge, whereas one element of knowledge may have multiple subjects (e.g., performance data about and specifications of material properties).

The taxonomies of Ropohl and De Vries seem to fare better in this respect. Neither includes a distinction between knowledge and skills, or between variously codifiable elements of knowledge. Instead, both authors refer, in different ways, to the distinction between structure and function. At first glance, this seems sufficiently principled to support mutual exclusiveness of categories. Yet problems ensue as soon as one looks for a more detailed understanding. For one thing, the notion of artefact function is far from uncontested, as Preston's contribution to this handbook makes clear; on some views, such as Robert Cummins' [1975], the function of an artefact may not be distinct from structural features, such as dispositions and other physical behaviour. These views may be contested qua theories of artefact functions, but this holds the two taxonomies hostage to an unresolved philosophical debate.

A second set of remarks concerns the manifest differences between the taxonomies, which roughly divide into two pairs. The systems of Vincenti and

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takes the form of constructing a taxonomy, and is frequently motivated by the quest for epistemic emancipation. It therefore makes sense to evaluate the taxonomical work in the light of this quest.

[15] Vincenti distinguishes these practical considerations from both tools and data because they "frequently do not lend themselves to theorizing, tabulation, or programming into a computer" and "they are hard to find written down" [1990, p. 217].

Faulkner, and those of Ropohl and De Vries, seem similar, but also show some notable differences. For the Vincenti-Faulkner pair, the similarities are easily explained, because Faulkner used Vincenti's (earlier) work as an explicit guiding line for her own investigation into innovation. Still, she added categories (e.g., knowledge about knowledge) and subcategories (e.g., new product ideas), removed others (e.g., quantitative data), and reshuffled still others (e.g., by combining in one subcategory both operational principles and normal configurations). Matching the taxonomies of Ropohl and De Vries is harder, given their terminological differences. Ropohl's functional rules, for instance, appear to match De Vries' process knowledge rather than his functional-nature knowledge. Still, that both authors distinguish a 'functional' category makes their taxonomies more alike to each other than to any of the other two.

These differences partly reflect differences in guiding principles. As is routinely noted in textbooks that deal with classification and categorizations, items can be grouped together in arbitrarily many ways. Cars, for instance, can be classified in terms of ownership (privately owned, rental, leased, etc.), fuel (gasoline, electrical, hybrid, etc.), engine type, colour, ownership history (first-hand, second-hand, third-hand, etc.) number of dents, etc. To curtail this arbitrariness, some guiding principle should be invoked. For many scientific classifications, it is required that its classes "function in, or facilitate the formation of, scientific laws".[16] This requirement is pointless in the present context, not only because the four taxonomies are reviewed for their emancipatory success, but also because some of them feature a *(sub-)category* of scientific theories and laws. Ropohl and De Vries instead use perspectives from the philosophy of technology: their taxonomies are guided by systems philosophy and the dual-nature thesis respectively. The other two taxonomies have no clear guiding principle: Vincenti's taxonomy seems largely the result of personal reflection on a large number of case studies in one, design-oriented discipline, namely aeronautical engineering, whereas Faulkner's additions and adaptations to Vincenti's system mainly stem from her studies into technological innovation.

I will return to this difference in guiding principles, or lack thereof, in the next section. For the moment, I note that this underlying difference means that one resolution of the manifest differences is unavailable. If two biologists agree on the criteria for speciation, but one distinguishes five species of dog, and the other distinguishes six species, a straightforward solution is that the former has overlooked one species. This resolution is probably not available for taxonomies of technological knowledge: the four systems cannot be merged into one super-taxonomy by distinguishing every category that is listed by at least one taxonomy. For one thing, this super-taxonomy would share the formal flaws of any original taxonomy; for another, it would require some possibly arbitrary decisions. De Vries, for instance, does not distinguish competences and know-how from theoretical or propositional knowledge. Given the other systems, he might have done so in two different ways: he might have followed Ropohl's example in listing know-how as a

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[16] David Hull, "Taxonomy", in the *Routledge Encyclopaedia of Philosophy.*

Vincenti [1990]	**Ropohl [1997]**
Fundamental design concepts - operational principles - normal configurations	Structural rules on the assembly and interplay of the components of a technical system
Criteria and specifications - general, qualitative goals[a] - specific, quantitative goals - goal-to-specification translations[b]	Technological laws transformation of natural laws with regard to technical processes
Theoretical tools - models and theories - intellectual concepts (e.g., 'boundary layer')	Functional rules what to do if a certain result is to be attained under given circumstances
Quantitative data - descriptive (e.g., operational conditions, human behaviour) - prescriptive (e.g., safety factors)	Technical know-how (implicit knowledge and skills)
Practical considerations - experience from production, operation, accidents - design rules of thumb	Socio-technical understanding systematic knowledge about the relation between artefacts, natural environment and social practice
Design instrumentalities - structured design procedures - ways of thinking (e.g., control-volume thinking) - judgemental skills	

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[a] This subcategory and the next are only implicitly distinguished by Vincenti.

[b] See Marc de Vries' contribution to this *Handbook* for a closer analysis of this subcategory.

Table 1.a

Faulkner [1994]	**De Vries [2003]**
Related to natural world • scientific and engineering theory • material properties	Physical-nature knowledge
Related to design practice • criteria and specifications • instrumentalities • fundamental design concpets • competence • practical experience	Functional-nature knowledge
Related to experimental R & D • experimental and test procedures • research instrumentalities • research competence • experimental and test data	Knowlege of physics-function relations
Related to final product • new product ideas • operating performance • production competence	Process knowledge
Related to knowledge • location of knowledge • availability of equipment, materials, facilities or services	

Table 1.b

separate category, or he might have included the distinction in the form of subcategories. Furthermore, only Ropohl explicitly lists "socio-technical understanding" as a category; this kind of knowledge is either missing from the other taxonomies, or very covertly included.

The third and final set of remarks concerns the way in which the taxonomies incorporate possible differences between scientific and technological knowledge. All taxonomies list categories or subcategories that largely, or even exclusively, appear to consist of run-of-the-mill scientific knowledge. Therefore, if the taxonomies serve the purpose of epistemic emancipation at all, they do so by *incorporating* scientific knowledge, rather than by contrasting an elaborately classified system of technological knowledge with a system of scientific knowledge. So, Vincenti includes models and techniques from mathematics and physics among his examples of theoretical tools; Ropohl's category of structural rules might, and De Vries' structural-nature knowledge definitely does, include many statements about physical or geometrical relations between artefact components; and Faulkner explicitly distinguishes scientific *and* engineering theory as a subcategory.

This incorporative strategy seems reasonable, if "technological knowledge" is taken to be the body of knowledge used in engineering science, design and/or practice; after all, engineers routinely use scientific theories and models. Still, the strategy creates at least two problems: one of a formal nature, and the other with respect to the goal of epistemic emancipation. Formally, as soon as one of the four taxonomies (or the super-taxonomy that results from combining them) is combined with a taxonomy of scientific knowledge, a taxonomy results that does not satisfy the demand of mutual exclusivity: some (sub-)categories will feature both in the technological and in the scientific part of the encompassing taxonomy. With regard to emancipation, it makes little sense to include categories of knowledge that answer to *scientific* standards — the resulting body of technological knowledge will certainly not be (completely) autonomous if these standards apply to part of it.

One may think to solve both problems at once by excluding from one's taxonomy of technological knowledge all categories that feature in a taxonomy of scientific knowledge. In this way, double entries are avoided, and one may still claim that the resulting science-less body of technological knowledge answers only to its own rules. The resulting taxonomy would remain silent on the nature of those rules — making the autonomy claim uninformative. What is worse, it would make the autonomy claim trivially true, by constructing technological knowledge as an epistemic system that is different from science. Thus, this solution might offer only formal consolation, without furthering emancipatory ends.[17]

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[17] This can be avoided if the identification of "genuinely technological" elements of technological knowledge is followed by an analysis of their epistemic character. Even then, however, one might do no more than make explicit one's intuititions regarding the epistemic differences between science and technology, since these intuitions might be presupposed in the identification of the "genuinely technological" elements.

Another, more roundabout solution would be to argue that the inclusion of knowledge from scientific disciplines such as mathematics and physics is only apparent. One might maintain that this knowledge is either selected from that available within the discipline by criteria that are unique to engineering science and design — meaning that the distinctive nature of technological knowledge features in the criteria of selection; or that scientific knowledge is adapted to engineering purposes — meaning that the distinctive nature of technological knowledge features in the content of every (sub-)category. Both of these options are familiar from Section 2: they are two ways in which the contrastive strategy for epistemic emancipation may be developed. This does not mean that this roundabout solution must come to naught. Yet it does mean that, as soon as "scientific knowledge" is included among the (sub-)categories of a taxonomy of technological knowledge — as in the four reviewed taxonomies — the taxonomical strategy for emancipation reduces to the contrastive strategy.

5 THE DOUBLE-DEMARCATION PROBLEM

Apart from the problems with individual taxonomies discussed in the previous section, there is a more general problem that needs addressing. This problem affects both the contrastive and the taxonomical strategy for epistemic emancipation.

To appreciate this general problem, it is worthwhile to consider the other end of the epistemic-emancipation problem: scientific knowledge. Suppose someone is interested in making a list of types of scientific knowledge, for instance to distinguish possible contributions to an encyclopaedia of science. There are various ways of organizing this classification, requiring some kind of principled decision, as discussed in the previous section. Suppose this decision is guided by the results of science, such as the lawlike regularities that form the backbone of scientific theories, or the theories themselves. Thus, one obtains entries about Newton's laws of motion or classical mechanics, about chemical bonds, or the regularities guiding supply and demand. In addition, a second decision is required, one that concerns the boundaries of scientific knowledge. One needs to decide why (not) to include controversial regularities, such as homeopathy's laws of similars and infinitesimals or the correlation between fossil-fuel consumption and climate change. And one needs to decide whether to include models and phenomenological laws, which merely describe and do not explain by referring to some underlying causal mechanism.

Without these decisions, one about the guiding classificatory principle and two about the boundaries of knowledge, a list of scientific knowledge would be arbitrary. Yet at least one of these decisions is notoriously hard to make in a principled way: the decision to exclude, for instance, the central tenets of homeopathy amounts, of course, to the familiar problem of demarcating science from pseudoscience, or unscientific knowledge. The failure of various purported demarcation criteria forms the backbone of many introductions into the philosophy of science. There may be characteristics that many sciences have in common, and some that most do not have in common with pseudo-science, nonsense or common sense; but if there is an acceptable, clear-cut criterion to be had, no-one has been able to formulate it. Fallibility, confirmation, prediction and explanation seem central elements, but philosophers cannot even agree on these elements, let alone on a slogan that captures them all.

This problem affects taxonomies of technological knowledge, if they are used for epistemic emancipation. Firstly, the negative experiences with demarcation in science provide inductive support for pessimism about similar inquires into technological knowledge. Thus, compiling an encyclopaedia of technological knowledge seems at least as arbitrary as the encyclopaedia-of-science project.

A complicating factor is that ‘technological knowledge’ is, to some extent, a technical term. Whereas ‘scientific knowledge’ sees a considerable amount of everyday usage, one seldom comes across descriptions of a model or research result as ‘technological knowledge’. This means that determining the boundaries of this type of knowledge may be, in a sense, easier than determining those of scientific knowledge. There may be entries that are beyond controversy, and some of these have been used as examples of technological knowledge in the literature: Vincenti’s [1990] control-volume analysis, Constant’s [1999] material-balance analysis, finite-element analysis, and Smith’s [1960] metallurgy all come to mind. Beyond the domain of those examples there is, undoubtedly, a grey area, but if ‘technological knowledge’ is indeed a technical term, this part of its extension may be determined by stipulation.

Although stipulations are, in this case, a legitimate way of solving boundary problems, they make fully explicit the arbitrariness of this constitutive rule for compiling a list of technological knowledge. To give two examples: all the paradigmatic entries mentioned above concern knowledge that is produced and employed by engineers, but technological knowledge might also conceivably include the instrumental knowledge that users possess about their cars and computers; and all entries mentioned above concern knowledge that can be expressed verbally, whereas much of our knowledge about technology appears to consist of know-how and competences. To be sure, one might resolve the latter issue by distinguishing ‘technological’ knowledge from ‘technical’ knowledge, where the latter consists of non-codified or non-codifiable techniques for achieving practical purposes. This is not only a stipulation, but also a distinction that does not seem to guide any of the taxonomies of technological knowledge currently on offer — all the examples reviewed in the previous section either explicitly include know-how and competences or, in De Vries’ case, do not exclude them. Thus, a taxonomy based on this distinction would be idiosyncratic, even if there is no rich tradition with which it would break.

To make things worse, the demise of demarcation as a philosophical research project affects the taxonomical strategy in another way. If constructing a taxonomy of technological knowledge is to serve the purpose of emancipating it from scientific knowledge, it should at least be clear in what principled way the taxonomy distinguishes both types of knowledge. There should, in other words, be a reason why some item is included in one list rather than another. It is possible to construct a list without first explicitly stating some criterion for including items: the list may be constructed extensionally, by including knowledge that is produced in an engineering context, or knowledge that concerns the use and design of technical artefacts. Still, if such a taxonomy of technological knowledge is to serve emancipatory purposes at some point, it encounters a double demarcation problem. It should put clear boundaries to the term 'technological knowledge' and, simultaneously, distinguish it from the equally vague term 'scientific knowledge'. Even philosophers without great sceptical inclinations might feel cagey about such an enterprise.

There may be clear and uncontroversial examples of scientific and technological knowledge, and these may serve as prototypes for distinguishing the two epistemic categories. However, the mere existence of paradigmatic examples does not solve a demarcation problem. Hardly any philosopher of science would deny that Newtonian mechanics and the knowledge compiled in your local phonebook may serve as paradigms for scientific and non-scientific knowledge. Still, a criterion is needed for evaluating borderline or otherwise disputed cases. Paradigmatic examples may be used to check candidate criteria, they do not supply them. If one seeks to establish that technological knowledge is autonomous, and if a taxonomy is to be useful for that purpose, one needs to determine what should be classified as technological knowledge, and what should not.[18]

As an illustration of the double-demarcation problem, consider the Carnot engine. This hypothetical artefact was first introduced by Carnot in his *Réflexions sur la Puissance Motrice du Feu* (1824). Our present-day description of it is largely based on Clausius' work in the 1860s. The engine has played a pivotal role in the development of, in particular, the concept of entropy, and it is a standard element of introductory textbooks on thermodynamics. Like any heat engine, the Carnot engine involves the conversion of heat transfer into mechanical work, in a completely reversible cycle (the Carnot cycle). Since, in reality, heat-engine cycles always create entropy and thus cannot be completely reversible, the Carnot engine is an idealization. It is, however, a useful idealization: it increases our fundamental understanding of heat-transfer processes, and it can be used to determine the maximal efficiency of thermodynamic engines.

If we were to construct a taxonomy of human knowledge, both scientific and technological, it is not clear how to classify the Carnot engine. That it should be classified is beyond reasonable doubt, since Carnot's work is generally regarded as a major intellectual achievement. Still, the engine is an idealization, putting Carnot's work squarely in the gray area of thought experiments. Moreover, it is

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[18] An alternative would be to examine whether the paradigmatic examples of technological knowledge, say Pambour's theory of the steam engine, is autonomous from scientific knowledge. This may be a viable and much-needed epistemological project, but it is much less ambitious than examining the autonomy of the entire category of technological knowledge. At most, studies into specific types of technological knowledge yield hypotheses about what might be epistemically distinctive about all technological knowledge. But to check this hypothesis, a complete inventory of technological knowledge would be needed, leading back to the (double) demarcation problem.

both the cornerstone of an important scientific theory, thermodynamics, and a (fictional) artefact that provides guidelines or limitations for the design of technical artefacts. As such, it seems to have earned its place in both the body of scientific knowledge, and that of technological knowledge. Nevertheless, Kroes [1992] classifies Carnot's theory about heat engines as scientific, contrasting it with Pambour's "engineering" theory on the basis of his definition.

One may have a principled reason to classify all our knowledge about Carnot engines as either scientific or technological, or some as scientific and some as technological — but the list itself does not make this reason explicit: one needs something like Kroes's definition. In this sense, a taxonomy requires a solution to the double-demarcation problem rather than providing it. Moreover, it seems that a principled reason should be, or can only be, derived from an in-depth study into the use and structure of idealizations in science and technology, or natural and engineering science. If the Carnot engine would be presented in exactly the same way in textbooks for physicists and engineers, and if statements regarding the engine would have the same epistemic value in both domains, classifying this knowledge as either scientific or technological would be an arbitrary decision: nothing would be at stake. In this sense, the taxonomical strategy for emancipating technological knowledge depends on the contrastive strategy — which was earlier shown to be underdeveloped.

6 TECHNOLOGICAL KNOWLEDGE AS TACIT

Using ideas and notions developed by Michael Polanyi [1958; 1966], some authors have emphasized the importance of tacit knowledge in engineering and technology.[19] They have argued, or stated, that part of the knowledge produced by technological practice is hard or even impossible to make fully explicit in declarative statements, but can only be acquired through personal experience. Some make tacitness part of their characterization of technological knowledge, e.g.: "(...) the knowledge of techniques, methods and designs that work in certain ways and with certain consequences, even when one cannot explain exactly why." [Rosenberg, 1982, p. 143] Others use technological practice to characterize tacit knowledge, e.g.: "(...) the implicit, wordless, pictureless knowledge essential to engineering judgement and workers' skills." [Vincenti, 1990, p. 198]

This emphasis on tacit knowledge is not exclusive to the philosophy of technology. In fact, most work on tacit knowledge and technology is done outside of philosophy. One field where this relation is especially prominent is that of knowledge management, where the communication and sharing of knowledge is a central concern (e.g., [Nonaka and Takeuchi, 1995; Choo, 1998; Baumard, 1999; Firestone and McElroy, 2003]). Other fields where tacit knowledge is an important point of concern are the design of expert systems (e.g., [Berry, 1987]) and studies of

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[19] Nightingale's contribution contains more details of the literature on tacit knowledge, and focuses on its possible importance for understanding engineering design, rather than for understanding the nature of technological knowledge.

technological innovations and technology transfer (e.g., [Nooteboom *et al.*, 1992; Senker, 1993; Howells, 1996; Leonard & Sensiper, 1998; Nightingale, 1998; Wong and Radcliffe, 2000; Salter & Gann, 2003]). Here, the appeal to tacit knowledge is typically used to indicate the firm-specificity and person-dependence of knowledge. It is stressed, for instance, that successful implementation of new technologies requires detailed and specific knowledge about a particular situation, which is — at least at first — only available through personal experience and rules of thumb (e.g., [Arora, 1996]). Other authors point out that, although codified and explicit knowledge is available for more established technologies, effective use still relies on skilled operators and maintenance personnel, arguably showing that there is an irreducibly tacit component in technological knowledge (e.g., [Noble, 1978]).

That many contributions to the literature on technological knowledge appeal to tacitness is beyond question; moreover, most do so by pointing out that it has been generally overlooked, because of an exclusive focus on codified knowledge, and that it is essential to a full account of knowledge. Thus, the existing literature seems based on the idea that there is something distinctive about tacit knowledge, and perhaps also something distinctively tacit about technological knowledge. This makes the appeal to tacit knowledge potentially interesting for the epistemic-emancipation project. Yet to see how and to what extent the appeal to tacit knowledge could improve our understanding of the nature of technological knowledge, and emancipate it from scientific knowledge, two questions need to be answered. Firstly: what is the relation between tacit and technological knowledge? Secondly: is the tacitness of technological knowledge more prominent or encompassing than that of other types of knowledge?

Insofar as these questions have (implicitly) been answered in the literature, the answer to the crucial second question appears to be negative. Let us tackle them each in turn.

Virtually everyone who writes on tacit knowledge, even those who do not ultimately use the term, agrees about one conceptual issue — that there is something about human knowledge that standard, justified-true-belief or propositional, accounts do not capture. Beyond this stage, however, there is considerable disunity about the appropriate concepts, concerning both the phenomenon of "tacitness" and the standard view(s) with which it supposedly contrasts. At least three distinctions are at issue in the literature. These distinctions are related, but different, and they are seldom distinguished as carefully as they should be. Firstly, there is, what might be called, the *psychological* distinction between implicit and explicit knowledge (e.g., [Dienes and Perner, 1999]; see also [Reber, 1993]).[20] One way to phrase this distinction is as follows: when we know a fact, we have an accurate representation of it. On the basis of its functioning and its accuracy, this representation may be identified as "knowledge" (rather than a desire). If we are

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[20] By calling this distinction 'psychological', I do not mean that it is a unanimously accepted part of contemporary cognitive or developmental psychology. This distinction is, however, mainly discussed by cognitive psychologists, and concerns the functioning of representations rather, e.g., than the justification of statements.

not aware of this representation, and its accuracy, the knowledge is implicit. By contrast, our knowledge concerning this representation is fully explicit. Phrased in this way, the psychological distinction is gradual, and all distinguished states involve representations. Secondly, there is a *grammatical* or *linguistic* distinction between two types of statements involving 'knowing': knowing that something is the case, and knowing how something can be done. This distinction is, of course, primarily associated with work by Gilbert Ryle [1949], and it is clearly language-relative. In some languages, like German and Dutch, this distinction is expressed by means of similar-sounding words ('kennen', as in 'Ich kenne *Der Zauberberg* nicht'; and 'können', as in 'Ich kann Schlittschuhlaufen', respectively) rather than one word; other languages may even use completely different words. Thirdly, types of knowledge may be distinguished *social-epistemically*, with regard to their communicability: knowledge that can be transferred exclusively through verbal communication, and knowledge that is not or cannot be so transferred — for instance, because it can only be acquired through personal experience. I will call the first type 'verbal' knowledge, and the second 'non-verbal'.

When introduced, the term "tacit knowledge" is typically used in the latter sense. However, the interconnections with Ryle's primarily grammatical distinction are particularly strong in the philosophical literature, so that the actual use of "tacit knowledge" is at least ambiguous in this respect. Even authors who do not explicitly refer to Ryle often use terminology reminiscent of his, and refer to the same stock examples, e.g., of riding a bicycle. Furthermore, connections are forged with the (folk-) psychological distinction between knowledge and skills. This is frequently equated with Ryle's distinction, and "tacit knowledge" is taken to refer to skills and "know-how". Much more may be said about this, but I will cut some corners in calling this distinction a red herring. The reason is that, as soon as the unicity and autonomy of technological knowledge is sought by assimilating it to skills, the epistemic-emancipation project becomes open to the objection that it is based on a category mistake. After all, if skills are *contrasted* with knowledge, and the difference between technology and science is based on this contrast, the sought (and perhaps found) difference cannot be epistemological: it is not a distinction between types of knowledge, but between knowledge and something else, e.g., action.

Thus, the frequent appeals to tacitness, and discussions of this phenomenon with regard to technology, suffer from multiple ambiguities in the very notion of "tacit knowledge", which affect its usefulness for the epistemic-emancipation project.

One may think that, while these ambiguities are being sorted out, a preliminary epistemological distinction may be made between fully explicit, propositional, verbal knowledge on the one hand, and the overlooked "tacitness" phenomenon on the other hand. This would, however, be naive, since a major epistemological distinction is concealed beneath the conceptual distinctions.[21]

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[21] This epistemological distinction is only occasionally made in the literature; see, e.g., [Gorman, 2002].

One possible understanding of tacit knowledge is as a *supplement* of the traditionally analyzed body of propositional knowledge. The associations with Ryle's sharp grammatical distinction, and with the knowledge-skill distinction facilitate this understanding. From a psychological perspective, this understanding is highly problematic: one may think up all kinds of cognitive processes that share characteristics of both types of knowledge, undermining the idea of supplementary, but autonomous bodies of knowledge. The internalization of calculation rules is, for instance, a process that shows how explicit, and highly verbalized procedures can turn into implicit routines through frequent exercise. This does not mean that the distinction is conceptually indefensible, but it does not have the immediate plausibility of Polanyi's original appeal to tacitness. Moreover, this understanding has the disadvantage of inviting the category-mistake objection mentioned above: if tacit knowledge is this skill-based supplement to propositional knowledge, why call it "knowledge" at all?

Therefore, some psychologists — and researchers in other disciplines who take psychological studies into account — prefer another understanding of the appeal to tacitness (e.g., [Wagner, 1987]). On it, our body of knowledge contains a tacit element, in all senses distinguished above: explicit knowledge must be based on implicit knowledge, which is at least conceptually prior; knowledge-that always involves knowing-how, since it involves, among other things, competence in reasoning; and verbal knowledge presupposes non-verbal knowledge, if only in the trivial sense that we cannot make fully explicit our speech patterns, including rules for appropriate utterances and other pragmatic aspects of language. Some passages in the writings of both Ryle and Polanyi suggest this understanding of tacitness — as a general aspect, component or 'dimension' of knowledge. And although this view requires substantial elaboration, it does not have the abovementioned disadvantages of the first understanding. Gradualism can be captured by analyzing knowledge as having a more or less prominent tacit component; and since tacitness is an integral part of all knowledge, it is an appropriate subject for epistemology.

This understanding of tacit knowledge answers the two questions posed earlier. Firstly, technological knowledge may be said to have a strong relation to tacitness. Both the knowledge possessed by designers and that possessed by users, and even the more theoretical models of engineering sciences involve a tacit component. Indeed, some examples in the general literature on tacit knowledge, such as Ryle's bicycle riding, are derived from the technological domain broadly conceived (albeit mainly from the user's perspective); and both design and use are clearly competence-based activities, easily described in terms of knowing-how. That they also involve knowing-that, and can in various degrees be verbalized does not run counter to the appeal to tacitness in this sense.[22]

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[22] On a gradualist understanding of tacit knowledge it is problematic to make in one's taxonomy a sharp distinction between competences and know-how on the one hand and "theoretical" knowledge on the other hand.

However, on this understanding of tacitness, there is almost by definition no *special* relation between it and technological knowledge. If the arguments of Ryle and Polanyi are sound, they would show that all knowledge contains a tacit component. And their general arguments have been supported by a host of more specific studies in cognitive psychology (e.g., [Reber, 1993]) and the epistemology of science. Like engineers, scientists are said to rely on rules of thumb in designing experiments and interpreting data, and to require personal experience in addition to theoretical education (e.g., [Collins, 1973, 1982; Senker, 1993; Sternberg and Horvath, 1999]). The works of Donald Schön [1983; 1988] also illustrate this generality. Some of Schön's examples are drawn from domains that might be called technological; and he often phrases his general claims by referring to "technical" problems or "design" contexts.[23] Yet Schön's claims regarding the importance of personal experience and improvisation concern professional practice in general, not engineering design in particular.

In sum, the literature on tacitness in technological knowledge shows a lack of conceptual clarity. Furthermore, insofar as clarity can be obtained, appealing to tacitness does not further the end of epistemic emancipation. Instead, it increases the burden of proof resting on those who want to establish emancipation through pointing out the role of tacit knowledge in technology: rather than showing that such knowledge plays a role, they should show that it plays a *distinctive* role.

7 SOCIAL SCEPTICISM

In this section, I will follow up my observations about ambiguities and lack of emancipatory arguments in the current literature with a general argument. This argument concerns the social-epistemic understanding of tacit knowledge, i.e., as knowledge that is not communicable by verbal means. This incommunicability may, in itself, not be a distinctive characteristic of technological knowledge; if all knowledge contains a tacit component, it is all impossible to make fully explicit by verbal means. What is more, there seems to be hardly any knowledge that cannot be made partially explicit. Even in the standard example of cycling, it is possible to state some rules concerning the use of a bicycle (e.g., "Sit on the saddle, and put your feet on the pedals"). Thus, there appears to be a spectrum, ranging from knowledge that can be almost fully expressed verbally to knowledge that is virtually inexpressible by verbal means. All knowledge claims, scientific, technological and other, are somewhere on this spectrum.

One might argue that technological knowledge is, on the average, more toward the inexpressible end of this spectrum than scientific knowledge; or that it occupies an interval more to the inexpressible end. Then, tacitness would be more characteristic for technological knowledge than for scientific knowledge, even though it

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[23] E.g., "It is not by *technical* problem solving that we convert problematic situations to well-formed problems; rather, it is through naming and framing that *technical* problem solving becomes possible." [Schön, 1988, p. 5; emphasis added]. Here, the context makes clear that Schön refers to problem solving in domains such as medicine and law as well as engineering.

is not a distinctive mark. To establish this, one might point to empirical research regarding technological innovations or technology transfer. In the literature, examples of which were referred to above, it is often stressed that tacitness creates transfer problems — problems that are key issues for knowledge management and the development of expert systems. If similar empirical results have been found for scientific knowledge, they have neither gained the same prominence nor set a similar agenda for new subdisciplines. Thus, one might conclude that these empirical studies show at least a gradual distinction between the two types of knowledge.

This empirical conjecture might very well be falsified. But let's accept it for the sake of the argument. For even if technological knowledge were relatively ill-expressed and scientific knowledge relatively well-expressed, this does not establish epistemic emancipation. The reason is that this empirical difference might not be the result of the nature of technological and scientific knowledge, but of the social organization of science and technology.

If every bit of knowledge is verbally expressible to some extent, verbally expressing it becomes not just a matter of degree, but also of practical interest. Take, again, the example of riding a bicycle. If someone is the only bicycle rider in the world, expressing one's knowledge of how to ride a bicycle would be of no, or at most of personal, interest. However, as soon as someone wants to learn another person how to ride a bicycle, verbal expression becomes relevant. Yet *how* relevant it is depends on a number of factors, including the capacity of the educated person to respond to verbal instructions, the difficulty of acquiring the competence without any verbal instructions (if anyone could ride a bicycle on first trial, verbal instructions for it become as useful as breathing instructions), and the educator's willingness to teach the competence without trying any verbal "shortcuts". The extent to which cycling know-how is expressible enters the equation somewhere, but it is hard to say where exactly. Assume that someone lives in a society where there is a high demand for cycling instruction manuals. In these circumstances, verbal expression of cycling competence is a socially, perhaps even financially, rewarding enterprise. It would be reasonable for cyclists to invest considerable time and effort into moving their knowledge of cycling further towards the fully-expressed end of the knowledge scale; if someone would succeed in making her implicit knowledge slightly more explicit, she might acquire an edge over competitors on the market for cycling manuals.

This example is fictional and rather trivial.[24] It does show, however, the close connection between epistemic, social and even economic aspects of the tacit component of knowledge. This connection was to be expected, since "tacit knowledge" can be defined as a social-epistemic concept. For this concept, verbal expressibility of knowledge, its actual degree of expression, the social need for expressing it

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[24] To take another example: "being a successful manager" is a difficult skill (if it is even one skill) to express verbally. Yet there is a substantial market for even the most partial verbal expressions, in the form of lectures and books about management. Thus, the amount of "expression attempts" may say little about the expressibility of skills and knowledge, and much about economic viability and social need of attempts.

(given a division of labour or of expertise), and economic interests in expressing it can and should be kept apart analytically. Yet it is difficult to decide which of the four factors must be invoked to decide where a knowledge claim is to be placed on the tacitness scale.

This difficulty arises in full force if one wants to explain the different places that scientific and technological knowledge take on this scale (remember that above, we assumed *that* they take different places, or occupy different intervals). Technological knowledge is acquired in a certain social context, in which it is more or less profitable to express this knowledge verbally. To take an extreme example: if engineering were an exclusively one-person enterprise, and if practically useful items were a highly valued commodity, verbally expressing one's knowledge of how to design these items would not be worthwhile and might even be disadvantageous. Suppose that, by contrast, there were no scarcity: all material needs were fulfilled by means of imperishable or very easily replaced artefacts, and human beings were virtually immortal. Then, the design of new artefacts could be an activity for artificers who merely want to satisfy their curiosity. These artificers might verbally describe to each other their design knowledge in excruciating detail — supposing they had nothing better to do.

To put it very roughly: the current social circumstances of engineering involve considerable scarcity, a marked division of labour between professional designers and end-users, heavy commercialization, an increasing amount of teamwork in design, a decreasing loyalty of employees to companies, and heavy competition between companies that design new artefacts. On the one hand, in these circumstances, verbally expressing design know-how (an important element of technological knowledge) is advantageous to companies to some extent, since it facilitates teamwork, and improves the continuity of design work despite job-hopping employees. Hence, knowledge management is an economically interesting enterprise. On the other hand, there is a point at which further verbal expression of design knowledge becomes economically uninteresting — the costs of further expression outweigh its benefits — or even potentially disadvantageous, because another company could conceivably steal the entire body of design knowledge. Thus, the actual degree of expression (or codification) of technological knowledge may be largely due to socio-economic circumstances, not to the nature of the knowledge involved.

The same argument may be given for scientific knowledge. Science shares many of the features of technology indicated above: there is scarcity of (epistemic) resources, a division of labour between researchers and laypeople, at least some commercialization, an increasing amount of teamwork in most disciplines, transfer of researchers between institutions, and competition between researchers and institutions. Yet there may also be differences. Following Merton's (1973) identification of instutional norms in science, one could maintain that scientists should communicate their results and the way in which they achieved them. Furthermore, the market for scientific research results probably has a different structure from the market for technical artefacts, especially if (again following Merton) one thinks that scientists cannot claim ownership of knowledge. As a result, the competition involved in science would be different from that in engineering. Consequently, the cost-benefit analysis for the verbal expression of scientific knowledge may also be different: the professional obligation to share results, combined with a possibly milder form of competition, may suffice to pull scientific knowledge towards the well-expressed end of the tacitness scale. Again, this place would then be explained by appealing to social circumstances rather than to any epistemically distinctive features of science.

A similar argument has been expressed by economists who are interested in tacit knowledge (e.g., [Cowan *et al.*, 2000; Balconi, 2002]),[25] and criticized by others [Johnson *et al.*, 2002]. In this section, I have stated this in a more general form, as a counterargument to epistemically emancipating technology from science by appealing to tacitness. This “social-skepticism” argument is vulnerable to several objections, including charges of misrepresenting and oversimplifying the sociology of both science and technology. Although it is probably guilty of those charges, the argument does not require empirical adequacy: it only purports to show that, even if science and technology might be on different ends of the sliding “tacitness” scale, this difference *might be* a result of the social organization of science and technology. Some sociological storytelling suffices to show this. As a consequence, this alleged difference in tacitness does not entail that science and technology are epistemically different.

To counter this argument, one needs to show that the alleged prominence of tacitness in technology is not only real, but also a matter of epistemic necessity rather than a social contingency. Given the state of confusion concerning tacit knowledge and the unwillingness of many sociologists of science and technology to make a clear distinction between social and epistemic matters, such a counterargument may be a long time in coming.

8 PRESCRIPTIVE KNOWLEDGE

One existing strategy for epistemically emancipating technology from science remains to be discussed. Consider the following quote:

> The engineer, and more generally the designer, is concerned with how things *ought* to be — how they ought to be in order to *attain goals*, and to *function*. [Simon, 1981, p. 7]

Science is allegedly descriptive because it is aimed at truth or empirical adequacy; by contrast, engineering is supposed to be at least partly prescriptive because it is aimed at changing reality: “(...) The modal mood of a pure scientist is largely

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[25] The former paper includes the following telling quote: “Any individual or group makes decisions about what kind of knowledge activity to pursue and how it will be carried on. Should the output be codified or remain uncodified? Are the inputs to be made manifest or latent in the production process? For an economist, there is a simple, one-line answer: the choices will depend on the perceived costs and benefits” [Cowan *et al.*, 2000, p. 214].

descriptive, while the mood of engineering is generally prescriptive" [Hendricks *et al.*, 2000, p. 278].

Some specifications of this difference reveal puzzlement and confusion rather than characteristics of technological knowledge. To give an example, Vladimir Hubka and W. Ernst Eder [1990] present a variety of types and forms of what they call "design knowledge" — an epistemic category that seems to overlap significantly with technological knowledge. Besides presenting a list of types and a diagram depicting connections between design knowledge and other areas, Hubka and Eder classify the types by means of two distinctions: that of product versus process, and that of descriptive versus prescriptive statements. These two distinctions are both useful and relevant.[26] However, Hubka and Eder undermine the quality of their analysis by next presenting "maps" of statements and knowledge [1990, Figs. 4 and 6] in which the distinctions are represented by orthogonal continuous lines, and individual contributions to design knowledge by areas within the graph. Representing the distinction between descriptive and prescriptive statements as a sharp dichotomy might be an oversimplification, but representing it as a continuous scale without any argumentation or even examples of intermediate cases "resolves" some thorny philosophical issues with, literally, a single stroke.[27]

Furthermore, some authors presume that pointing out the presence of prescriptive statements in technological knowledge suffices to differentiate it from scientific knowledge. Taken literally, this is incorrect. Paradigmatic examples of scientific knowledge, such as physics, comprise prescriptive as well as descriptive statements. A widely used textbook on electrodynamics,[28] for instance, contains prescriptive statements such as: "It is *useful* to keep track explicitly of the total fields propagating in the two directions", "Because of the generality of the contribution from the shadow region, it is *desirable* to consider it separately" [Jackson, 1975, p. 372, p. 448; emphasis added]. One might object that engineering texts contain a greater proportion of prescriptive statements, or more prominent ones. Indeed, the statements above were collected from a substantial sample of a large textbook. Yet making this supposed feature of technological knowledge into a topic of textual statistics is not exactly clarifying the issue at hand.

Alternatively, one might attempt to convert the prescriptive statements in the physics textbook into descriptive ones, such as: "An accurate description of the propagation depends on $A(\omega)$ as a function of complex ω" or "A general model is obtained once one considers separately the contribution from the shadow re-

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[26] This essay does not consider the product-process distinction. Yet an analysis of technological knowledge is bound to include it, given the product-process ambiguity of the central notion of "design" and of "technology" itself.

[27] To do Hubka and Eder justice, it should be remarked that their [1990] paper is a brief summary of a significant body of work on design knowledge. Yet the continuous-line diagrams also appear in other work, e.g., [Hubka and Eder, 1988], without lengthier arguments for choosing this particular representation.

[28] A handbook on a highly theoretical part of physics was chosen to prevent the objection that all sample prescriptive statements are engineering intrusions in science, related to the design of experiments or the interpretation of their results.

gion". This conversion does not show that these statements given above were pseudo-prescriptive, i.e., that they can be reduced to descriptive statements. For to capture their meaning fully, explicitly prescriptive statements concerning accuracy and generality should be added: knowledge of $A(\omega)$ as a function of complex ω is only *required* if accuracy is a guiding value, and separate consideration of the shadow region is only *desirable* if generality is a desideratum. Hence, closer analysis of the prescriptive statements from physics shows that they presuppose scientific values such as empirical adequacy and generality. Therefore, analysis of prescriptive statements from physics and engineering may well return us to familiar grounds, namely the TU-intuition that science is directed towards truth and technology towards usefulness (see Section 2). Because this intuition is primarily one of values, it is only to be expected that handbooks from both physics and engineering contain prescriptive statements, but that these are related to the *different* central values of the disciplines.

To go beyond restating the TU-intuition, one should do more than note prescriptive statements in technology, or their relation to the goal of usefulness or changing reality. One way to do this is to analyze the fact that technological knowledge is not about just any change in reality, including the diffusion of gases or the construction of theories, but about deliberate changes that serve practical purposes. This analysis starts from the seemingly trivial observation that technology is related to human, intentional actions. Most technical artefacts and processes do not occur naturally, but need to be designed and manufactured. Few artefacts realise their functions automatically, but require active manipulation by a user. And even artefacts that function more or less automatically, such as fire alarms or assembly-line robots, require monitoring and maintenance. Because technology is intimately action-related, it makes sense to assume that technological *knowledge* is related to designing, using and other actions as well. Moreover, since the goal of technology is to make useful changes in reality, these actions cannot just be described, but they must also be prescribed. To employ a car or an assembly-line robot, a user has to know not only for which purposes the artefact may reliably be used, but also which actions he or she should take, might profitably take when certain situations arise, or how to recognize undesirable behaviour of the artefact. In short: the practical aim of technology implies that technological knowledge prescribes and recommends intentional actions. It does not just describe what is the case, or what is desirable, but also what human beings should do to bring this desirable state of affairs about. This forges an intuitive distinction between technological knowledge and knowledge gained in the behavioural and social sciences, which seem primarily descriptive.

Given this starting point, a closer analysis of technological knowledge may employ (and require) action-theoretical resources rather than notions and perspectives borrowed from traditional epistemology or philosophy of science. Hence, one may look for teleological notions such as "goal" and "function";[29] one may

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[29] See Preston's contribution to this Handbook.

study the role of practical reasoning;[30] and one may investigate the status and justification of rules and recommendations in technological knowledge. This shift of perspective is non-trivial, especially given the goal of epistemic emancipation. Studying the distinction between scientific and technological knowledge by using notions and perspectives developed for understanding the former leads to questions like those posed at the end of section 2. As said there, few enough attempts have been made to answer these questions. Moreover, emancipation may require a different perspective altogether: action-theoretical terminology might be more appropriate for an understanding of technological knowledge than it is for an understanding of scientific knowledge.

One attempt to develop such an understanding is made by Mario Bunge. According to Bunge, one characteristic product of the engineering sciences is a *technological rule*, "an instruction to perform a finite number of acts in a given order and with a given aim" [1967, p. 132]. An example would be "If you are interested in comfortable private transportation, drive a car", where driving a car is a specific series of actions: getting in the driver's seat, starting the car, etc. Similar rules may be specified for other goals and action types, including design and maintenance.

As it stands, this way of characterising the prescriptive content of technological knowledge is rather broad and non-specific. The description given in the quote above applies to all practical rules, including: "When you are caught in a thunderstorm, avoid trees and large bodies of water and roll up in a ball". Taking technological knowledge as a part or a continuation of such common-sense practical knowledge may be correct as a first approximation, like taking science to be the continuation of common sense, but much work remains to be done to go beyond this first approximation.

indent Bunge does that by explaining how technological rules are, in the engineering sciences, *grounded* in scientific knowledge and elaborately tested, leading to a tremendous growth in reliable and productive rules after the Industrial Revolution. In this way, technological knowledge may indeed be distinguished from run-of-the-mill practical rules,[31] but Bunge's choice has a high price: the "grounding" claim regarding technological rules has made Bunge's work a standard target in the applied-science debate. Moreover, it seems to have made people so suspicious of the notion of technological rule that critical analyses have been screened-off by criticisms of Bunge's supposed applied-science thesis.

Yet it may be possible to employ the notion of technological rule without accepting Bunge's claims regarding grounding. One possibility is to consider the role of artefacts in such rules. Many practical rules, like the one concerning thunderstorms, involve only our own body; others, like "Do not drink salt water, even if

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[30] See Hughes' contribution to this Handbook.

[31] Still, if being grounded in scientific knowledge is to serve as a distinguishing characteristic, it should subsequently be clarified how instructions for driving a car are so grounded, whereas instructions for avoiding death by lightning are not. It is not clear whether even a gradual distinction may be gained in this way.

you are very thirsty", involve our bodies and natural objects. Whether these rules are grounded in scientific knowledge or not, they seem to involve techniques, rather than technology. By introducing artefacts, Bunge's characterization of technological rules may be amended into "instructions to perform a finite set of actions, including manipulations of one or more artefacts, in a given order and with a given aim".

This idea of technological rules has been developed, in different terms from Bunge's, by Pieter E. Vermaas and myself. The central notion in this line of research is that of use plans, "goal-directed series of considered actions, including manipulations of one or more artefacts" [Houkes and Vermaas, 2004]. Both use — the execution of use plans — and design — the construction and communication of use plans — can be analysed in terms of this notion [Houkes *et al.*, 2002]. The resulting perspective on technology and technological knowledge emphasizes goal-directed, intentional actions and the standards of (instrumental) rationality for these actions rather than the objects employed in such actions. It considers descriptive knowledge only insofar as it plays a role in intentional actions. Consequently, it provides action-theoretical resources for analysing the prescriptive content of technological knowledge.

The use-plan account provides a picture of prescriptive technological knowledge that is richer than the notion of technological rules alone. Knowledge regarding use plans need not consist only of instructions: they might carry both stronger and weaker normativity. Artefacts may be used in many different ways, not all of which may or can have been envisaged by their designers. The use-plan account incorporates this by a liberal notion of design. Everyone, engineers and consumers alike, can design in the sense of constructing and communicating use plans. One need not have a degree in engineering to use an empty milk bottle as a vase — use that is as effective and efficient as it is widespread. Knowledge regarding this use may be regarded as technological, in the minimal sense that it concerns use of an artefact for a practical purpose. The corresponding knowledge, that milk bottles can be used for holding flowers, is normative [Houkes, 2006], but involves a recommendation in some circumstances rather than an instruction.[32] Other knowledge regarding artefact functionalities involves requirements, which are considerably stronger than instructions. To give an example: some use is regarded as (im)proper, meaning that it is privileged over other ways of using an artefact. Such privileges may be analysed by referring to the fact that, although many agents are capable of designing, only some of them are professionally engaged in it. Their use plans are standardized and often even embedded in legal systems: many warranties, for instance, are declared void in cases of improper use. Thus, the use of artefacts is embedded in a (largely un-analyzed) system of rules, recommendations and requirements that is far richer than mere sets of instructions for attaining a goal.

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[32] See Franssen's contribution to this Handbook on artefacts and normative judgements for a more detailed analysis.

Furthermore, the use-plan account may be employed to study the relation between prescriptive and descriptive statements regarding artefacts. That there is such a relation seems beyond doubt: prescriptive statements that are not, somehow, related to accurate, propositional knowledge are at best very risky recommendations. Moreover, professional designers, engineers in particular, often possess knowledge about the physicochemical composition of artefacts, and design artefacts on the basis of this knowledge. On the use-plan analysis, one way in which prescriptive and descriptive statements regarding artefacts are related is by means of a specific type of explanation for the function of an artefact [Houkes, 2006; De Ridder, 2006]. In such 'technological' explanations, descriptions of the structure of an artefact are related to descriptions of the actions included in the use plan of the artefact, to show that these actions can be rationally expected to lead to realization of the goal state. That there are these explanations does not mean that prescriptive statements should be grounded in scientific knowledge, let alone that they are little more than "applications" of this knowledge. Some communicated use plans are, for instance, based on successful tests in a variety of circumstances, on trial-and-error, or simply handed down through generations of users [Vermaas and Houkes, 2006].

To conclude, the distinction between descriptive and prescriptive statements is in itself insufficiently specific for epistemic emancipation of technology. However, a closer analysis of some prescriptive statements made within a technological context — technological rules or recommendations and requirements regarding artefact use — might reveal a connection to intentional actions and practical (instrumental) rationality specific to technology. This analysis of prescriptive statements is still rudimentary, and it warrants further attention, even independently from the quest for epistemic emancipation.

9 OUTDATED EMANCIPATIONISM

The review of the existing literature in the previous sections shows that there are several ways in which authors have tried to establish epistemic emancipation. Few ways are developed beyond the embryonic stage, none have given rise to elaborate discussions and refinement of points of view and arguments. What is perhaps most important, all have so far failed to establish strong emancipation. For some attempts, general arguments can be offered that appear to show that they are bound to fail; for others, analysis shows that specific issues need to be addressed — more specific issues than those covered by existing efforts.

The results of the review are, in short, not encouraging. Establishing epistemic emancipation appears to require a concentrated, collective effort, aimed in part at overcoming some general counterarguments. It might, therefore, be understandable that historians and philosophers of technology have shifted their attention towards other topics: substantial effort would be needed to get the topic of the nature of technological knowledge off the ground, and the benefits might be so small that research time is more efficiently spent otherwise.

Additional discouragement is given by an increasingly powerful movement in the literature on the history, philosophy and sociology of science and technology. The 1970s and 1980s not only saw a decline in the interest for technological knowledge, and the conceptual and epistemic distinctions between science and technology. During these decades, an alternative perspective and research agenda was promoted in the newly developed field of Science and Technology Studies (STS). This chapter is not about the history, central characteristics and many divergent results and approaches within this field. Yet it is beyond doubt that traditional epistemic issues are not high on the agenda of research in STS,[33] and that many conceptual distinctions are typically regarded as outdated, or topics for deconstruction. Of particular interest here is that the distinction between science and technology has been subjected to criticism and revision, on the basis of both empirical, sociological research and more conceptual and methodological concerns. Many authors, including Don Ihde [1979; 1991], Bruno Latour [1987; 1993] and Andrew Pickering [1995], have pointed out or argued that scientific knowledge is not just historically and socially situated, but that it is acquired, distributed and defended in an increasingly intricate technological context. Scientists use technology to perform experiments, to manipulate and store data, to write research papers, and to communicate with other scientists. Many of these technological aspects of science are not merely contingent characteristics, but appear to be essential for science as it is conducted nowadays.[34] Since the 17th and 18th century, science has been experimental and mathematical — but since the 1950s experimentation and mathematization increasingly depend on technologies such as lasers, computers, and satellites. For the authors mentioned above, and many other STS researchers, the role of technologies in scientific research is so prominent and inalienable that they prefer to speak of "technoscience" rather than "science".[35]

Suppose that the main idea behind this neologism is correct, and that scientific knowledge can indeed not be studied in isolation from its technological context, because it is necessarily embedded in it. Then it may still be possible to emancipate technological knowledge with respect to scientific knowledge. After all, technology is not equated with science. There may be reason, also from a sociological point of view, to assume that technological knowledge is acquired, distributed and defended independently from scientific research.[36] There may be institutional

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[33] Here, "traditional epistemic issues" means the issues regarding (among other things) truth, justification and epistemic virtues that characterize epistemology as studied in the Anglo-American analytical tradition, and as reviewed in introductory books such as Audi [2002] and the essays in [Greco and Sosa, 1998]. Parts of the STS research agenda are and can be labeled as "epistemology" as well; take, e.g., many of the papers published in a journal such as *Social Epistemology*.

[34] One clear expression of this sentiment is: "Modern Science, in contrast to its ancient and more contemplative origins, [is] *essentially and necessary embodied in technologies, instruments*." [Ihde, 1993, p. 74; original emphasis).

[35] Here, "technoscience" indicates specifically a system in which scientific research cannot be studied in isolation from its technological context. The notion is used in a broader variety of senses in the literature.

[36] Many technoscience scholars claim that there is a reciprocal dependence relation between

cross-connections, but if anything, these show that technology deserves closer epistemological attention, because it is so important for scientific knowledge. Yet epistemic emancipation of technology from science no longer makes much sense: the model of science as epistemically autonomous from technology needs to go, along with any epistemology based on this model. Therefore, there is no standard epistemology left with which to contrast an analysis of technological knowledge. To put it crassly: why argue that technological knowledge is autonomous from science, when scientific knowledge is thoroughly technological?

The same point may be made by looking at the thesis that technology is applied science, which shaped so much of the literature on technological knowledge. If research on technoscience is correct, the thesis is at least unilluminating. The thesis conceals that (techno-)scientific research consists of the application of technologies, and may be shaped to a large extent by promises and expectations of future technological rewards. Technology may, in turn, be based in part of applying scientific theories, but this feature cannot be used as its most basic characteristic. The typical argument offered against the applied-science thesis is that some technologies have been developed without the aid of scientific theories. From the technoscience perspective, the argument is correct, but it ignores the deeper insight that scientific research is thoroughly technological — and it might in this way reinforce the mistaken epistemology that regards science as autonomous.

These observations offer plenty of reasons to revise our understanding of the relation between science and technology, but no reasons to ignore the study of technological knowledge. On the contrary, they make analyzing the acquisition, distribution and defence of this kind of knowledge far more important than it would be on either the applied-science image or the autonomy image. After all, understanding the epistemology of contemporary technology, together with that of science, would be crucial to understanding technoscience. However, the quest for emancipation, which shapes virtually all work on technological knowledge, should be abandoned: it involves a false assumption about present-day scientific and technological research, and is therefore outdated.

This line of thought offers a sociological or “empirical” counterpart to the more analytical counterarguments and problems presented in earlier sections. Together, I think they give ample reasons to abandon the quest for epistemic emancipation: whatever technological knowledge is, and from whatever perspective one wants to study it, one should not try to understand it as an epistemic category that is different from that of scientific knowledge.

Before I tentatively suggest an alternative research agenda in the concluding section, let me address a question that might be raised by the previous reflections on technoscience. The question is: why did technoscience scholars not start to study technological knowledge afresh, given its importance for understanding the very phenomenon that they describe? They may have reasons to abandon

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contemporary science and technology, so that modern technology cannot be studied in isolation from scientific research. This claim may be true, but it is stronger than the earlier claim about science alone.

the applied-science thesis, the ideal of epistemic emancipation, and perhaps traditional epistemology. Yet they have not replaced these views with an empirically informed, up-to-date epistemology of technology. Indeed, the very notion of "technological knowledge" is sorely lacking in the technoscience literature. Given the previous reflections, this is an oversight. One might speculate about the causes of this oversight. Perhaps the analysis of technological knowledge was so firmly associated with the misguided applied-science debate and the isolationist model of science that, in promoting a different perspective, STS researchers unwittingly threw away the baby with the bathwater. Surely, the abandonment of other traditional philosophical views, such as the fact-value distinction, makes it difficult or outright impossible to develop some of the more promising routes considered in this chapter. Understanding technological knowledge as prescriptive would, for instance, become as misguided as the applied-science thesis. Whatever the causes may be, I do not think that they offer sufficient reasons: technoscience scholars ought to analyze both technological and scientific knowledge, and their mutual dependence, just like philosophers of science and philosophers of technology should. It is time to give some indication how this analysis is still possible and useful in spite of the criticisms levelled at previous attempts.

10 AFFIRMATIVE ACTION AND FUTURE PROSPECTS

To conclude, I review the possibilities for making a fresh start in studying the nature of technological knowledge. I firmly believe that these possibilities exist. Besides criticisms, the preceding sections already contained some suggestions for future research. This section lists them again, by way of recapitulation, and adds several more general topics of research as well. Work on one or more of these topics might achieve weak epistemic emancipation of technology. The problems raised in the previous sections may not amount to fatal counterarguments and, in any case, mainly raise obstacles for strong emancipation. This leaves room for establishing a weaker claim.

Even if one feels justified in abandoning the emancipation project altogether, there is still sufficient reason to develop the topics below. Not putting emancipation as first — or even only — item on the research agenda, but showing that epistemically interesting results may be gained by studying technology would constitute affirmative action. It would show philosophers that technology has been unwisely ignored, not because it is fundamentally different from science, but because good philosophical work can be done on it.

Topics for further research proposed in previous sections include:

- The role of practical usefulness (rather than truthlikeness) in validating theories and models developed in the engineering sciences (Section 2).
- The role of practical usefulness in explaining the way in which theories and models from the natural sciences are adapted for use in the engineering sciences (Section 2).

- Possible distinctions between scientific concepts and technical concepts in engineering theories (Section 2)
- The different role of idealizations and hypothetical objects such as the Carnot engine in the natural and engineering sciences (Section 2; Section 5).
- The relation between features of technological knowledge (e.g., tacitness) and the social organization of engineering (Section 7).
- The distinction between technological rules and everyday techniques (Section 8).
- The inherently prescriptive or, more broadly, normative content of technological knowledge (Section 8).

In addition, the following two topics may be explored:

Technology and the nature of knowledge

The epistemology of technology has mainly been studied by considering technology as knowledge. Yet this does not exhaust the possible relations between technology and knowledge. As the sketchy review of research in science and technology studies in section 9 shows, technology is also related to knowledge, scientific and other, by providing much of the context in which knowledge is acquired, distributed and defended. These roles may be regarded as belonging to the context of discovery, and therefore rejected as a proper subject of epistemological studies. Yet they also require evaluation. Some of this evaluative work is done in what has been called the "philosophy of scientific experimentation" (e.g., [Radder, 2003]), in which the epistemic role of experiments and the technological devices used therein are studied.

An even less explored topic is the extent to which new technologies allow researchers to acquire and support knowledge in hitherto unprecedented ways. The sciences nowadays do not only rely on technologically ever more complicated experiments. Scientific observation is not just theory-laden, but has become, perhaps irreversibly, technology-laden as well. Software is used to gather, manipulate and graphically represent data, and both natural and social scientists are trained in using computers to solve mathematical problems. Some of these problems might have been solved, with considerable effort, by some unaided human brains; in other cases, computers apply approximation techniques on a scale that is at least practically impossible to achieve for human beings; and in a growing number of cases, computers solve problems that have proved humanly intractable. This epistemic use of technology resembles its use for, e.g., transportation: in some cases, it is merely convenient, like driving to the supermarket instead of walking; in others, it is clearly more effective, like crossing the Channel — which some gifted individuals can do swimming, but most of us cannot; in still others, like flying to the moon, it is indispensable.

The use of technology in scientific research might lead to particular methodological questions, e.g., concerning automated proof systems. It also leads to epistemological issues. One such issue concerns possible new, technologically generated sources of justification. A prominent example is the use of simulations to support scientific hypotheses, e.g., about climate change. Intuitively, computer-aided simulations do not provide observational data, like radio telescopes; nor do they involve approximation techniques that could, in principle or to a limited extent, be applied by human researchers. Instead, simulations are partly based on the theories and models used to construct them; but they also offer new insight into, and possibly evidence about, complex phenomena like turbulence [Winsberg, 2001; 2003]. Yet since simulation techniques occupy some middle ground between theory and observation, whatever evidence they offer is of an ill-understood type. More attention to the mathematics and technology of simulations is needed to clarify their epistemological status. The present neglect of simulation techniques in the philosophy of science jars with their increasing importance in all kinds of sciences.

The grounding of technological knowledge

In the philosophy of technology, studies of the relation between science and technology have been dominated by the applied-science debate. One unfortunate consequence of this domination, noted above, is that the notion of "technological rule" has become firmly associated with the thesis that engineers merely apply scientific knowledge. This has screened off this notion from further development. It has also precluded the development of alternative models of the relation between science and technology — models that might incorporate the fact that engineers frequently *do* apply scientific knowledge, or are at least trained in understanding and applying theories like thermodynamics and classical mechanics.

Outside of philosophy, however, interest in such models continues. To give one example, in *The Gifts of Athena* [2002], Joel Mokyr seeks to explain the sustained economic growth since the Industrial Revolution — a project that is squarely outside philosophy. However, the basis of his explanation is that science and engineering have since the early 19^{th} century undergone an unprecedented period of mutually re-inforcing progress. To develop this explanation, Mokyr uses both evolutionary terminology, which need not concern us here, and an epistemological model. In this model, he distinguishes two types of knowledge, in a way that is reminiscent of both Ryle and Bunge: knowledge can be propositional or prescriptive, where the former involves *any* proposition, and the latter both rules and skills. Moreover, prescriptive knowledge can be grounded in propositional knowledge, either minimally (we support adding some old leavened dough to fresh dough because we know that this procedure has successfully produced leavened bread in the past) or more elaborately (we know that there are starter cultures of yeast in the old dough, which cause fermentation). Mokyr's hypothesis is that the Industrial Revolution came about when more prescriptive knowledge was grounded in an elaborate way, leading to new techniques (e.g., the isolation of pure cultures of yeast), which in turn led to new scientific developments, which allowed additional grounding of techniques, etc.

Let us assume that this model fulfills a real need in its field. Then, a closer philosophical analysis of technological knowledge contributes directly to non-philosophical aims. For Mokyr's model does not analyze the grounding relation in detail. Moreover, it suffers from overly tolerant definitions of both propositional and prescriptive knowledge, making the problem of their relation almost into an artefact of the classification.[37] Because of these unclarities and idiosyncracies, the model is vulnerable to the objection that it merely revives the applied-science thesis, and that it is based on epistemologically problematic distinctions, such as Ryle's.

This should not lead epistemologists and philosophers of science and technology to ignore models such as Mokyr's. Instead, I think these models show that there is a need to develop a realistic, epistemologically refined analysis of the grounding relation — and of the ways in which technological knowledge and rules may *not* be grounded in scientific knowledge. This analysis should not be grafted on either the applied-science thesis or the epistemic-emancipation ideal. The previous section may have shown that these influences are hard to avoid. Yet this does not make the analysis any less needed: it only makes it more of a philosophical challenge.

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[37] Mokyr admits that his model might not stand up to critical analysis, which only makes the need for such an analysis more apparent.

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