The Status of Technological Knowledge in the Scientific Mosaic

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Keywords

theoretical scientonomy, technological knowledge, descriptive, normative, explicit, implicit, explicable-implicit, inexplicable, propositional, non-propositional

Abstract

In this paper, I argue that there is accepted propositional technological knowledge which appears to exhibit the same patterns of change as questions, theories, and methods in the natural, social, and formal sciences. I show that technological theories attempting to describe the construction and operation of artifacts as well as to prescribe their correct mode of operation are not merely used, but also often accepted by epistemic agents. Since technology often involves methods different from those found in science and produces normative propositions, many of which remain tacit, one may be tempted to think that changes in technological knowledge should be somehow exempt from the laws of scientific change. Indeed, it seems tacitly accepted in the scientonomic community that, while scientific communities clearly accept theories, technological communities merely use them. As a result, scientonomy currently deals with natural, social, and formal sciences, and the status of technological knowledge within the scientonomic ontology remains unclear. To help elucidate the topic, I propose that the historical cases of sorting algorithms, telescopes, crop rotation, and colorectal cancer surgeries confirm that technological theories and methods are often an integral part of an epistemic agent’s mosaic and seem to exhibit the same scientonomic patterns of change typical of accepted theories therein. Thus, I suggest that propositional technological knowledge can be part of a mosaic.
Introduction

The question of the status of technological knowledge was first formulated within the scientonomic context by Sean Cohmer during the seminar of 2015. Specifically, Cohmer inquired as to why technological knowledge was omitted from scientonomic discourse and how it could be included as part of a mosaic. After all, there seems to be a vast body of knowledge concerning both physical and social technology, such as “x is a useful bridge-building technique”, or “y is an efficient technique of consensus decision-making”. Thus, the task is to clarify the status of this technological knowledge and determine if it can indeed be included into the ontology of scientific change.

According to the position tacitly accepted by the scientonomic community nowadays, technological theories can only be used in practical applications but not accepted (Barseghyan, 2015, p. 31). The challenge for integration of technological knowledge into the ontology of scientific change is twofold. First, it needs to be shown that technological knowledge can be accepted and not merely used. Second, there should be some evidence showing that changes in technological knowledge are subject to the same laws of scientific change that describe changes in scientific theories and methods. The first step is especially important: it wouldn’t suffice to show that technological knowledge obeys the laws of scientific change without first establishing that technological theories can be accepted and not only used. After all, while technological theory change following the second law might very well indicate that these theories are, in fact, accepted, it could also be taken as evidence to suggest that used theories might also follow the second law, or suggest a similar relation between used theories and the community’s methods for determining which should be used and when.

Thus, I will first show that technological theories can be, and often are, accepted by epistemic agents. I will illustrate this by discussing the case of medieval agricultural knowledge on crop rotation. Then, I will discuss some preliminary considerations suggesting that technological knowledge changes in accord with the laws of scientific change. Specifically, I will address and deflect three potential arguments allegedly suggesting that patterns of change in technological knowledge should somehow be different. Finally, I will present some historical evidence from sorting algorithms, telescope engineering, and surgical treatment of colorectal cancer all suggesting that changes in technological knowledge seem to exhibit the same patterns as those from natural, social, and formal sciences.

Can Technological Knowledge be Accepted?

According to the currently accepted scientonomic ontology of epistemic stances, theories can be accepted, used, and/or pursued. A theory is said to be accepted if it is considered the best available description or prescription of its domain (Sebastien, 2016). Accepted theories are part of the scientific mosaic of the respective epistemic agent. As such, current theoretical scientonomy attempts to trace and explain changes in these accepted theories. In contrast, a theory is said to be used if it finds some practical application (Barseghyan, 2015, p. 31). The usefulness of a theory is essentially its instrumental value: a theory might be used without necessarily being accepted as the best available description of its domain (Barseghyan, 2015, p. 31). Moreover, used theories are often incompatible with one another, whereas accepted theories (and all elements in a mosaic) must be compatible as per the zeroth law. Finally, a theory is said to be pursued if it is considered worthy of further elaboration (Barseghyan, 2015, p. 31). While we often accept, use, and pursue the same theory, this is by no means mandatory; an epistemic agent can easily pursue a theory without either using or accepting it.

Now, one possible consideration against including technological knowledge in the scientonomic ontology has to do with the alleged inability of technological theories to be accepted. After all, while the goal of science is “to understand the world as it is, technology aims to change the world” (Franssen, Lokhorst, & van de Poel, 2015). Thus, our opponents may argue, technology produces no accepted theories of its own but merely uses theories in practice.

The view that technology is aimed at practical usefulness, whereas scientific knowledge is aimed at truth has deep roots in the philosophy of technology literature. This is essentially the view that Houkes calls ‘truth vs. usefulness’ intuition (Houkes, 2009, p. 312); its manifestations can be found in many traditional sources. Thus,
according to Skolimowski, “science concerns itself with what is, technology with what is to be” (Skolimowski, 1966, p. 373). Similarly, according to Hindle, “science seeks basic understanding [whereas] technology seeks means for making and doing things” (Hindle, 1966, p. 4). Jarvie concurs that technology “aims to be effective rather than true” (Jarvie, 1972, p. 55).

In scientonomy, it might be tempting to interpret this basic intuition along the lines of the acceptance/use distinction: scientists accept theories, while technologists merely use them. This is likely the interpretation that led to the initial omission of technological knowledge from scientonomic discourse. Yet, I believe, such an interpretation is misleading. The claim that technologists and scientists have distinct goals says nothing about what types of epistemic stances they take towards theories while pursuing those distinct goals. Even if we were to assume that the sole goal of technology is to change the world, it would still tell us nothing about the existence or non-existence of accepted technological knowledge. Thus, the question that interests us here is not what the respective goals of science and technology are, but whether there is such a thing as accepted technological knowledge.

In fact, the current stance of the philosophy of technology community on the latter question seems to be unequivocal: while technology often uses scientific theories in practical applications, there is more to technology than mere applied science. Thus, according to Wise, the historical record goes against the view that treats “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). Vincenti agrees with Wise: “technology appears, not as derivative from science, but as an autonomous body of knowledge, identifiable different from the scientific knowledge with which it interacts” (Vincenti, 1990, pp. 1-2). Pitt expresses the same view: “we have good reasons to believe that we should not characterize technology as merely applied science. It is does not follow from the fact that science and technology each has occasion to rely on the other, nor that one is a subset of the other” (Pitt, 2001, p. 22). According to Layton, the view that technological knowledge is more than mere applied science can be traced to Alexandre Koyré (Layton, 1974, p. 40; Houkes, 2009, p. 310). Thus, the existence of accepted technological knowledge doesn’t seem to be controversial.

The case of agricultural knowledge of crop rotation in the Middle Ages illustrates that there is more to technological knowledge than mere use. Farmers have known for thousands of years that when cereal crops such as wheat or rye are cultivated on the same field for several years in a row, they gradually deplete the soil and, as a result, the yield steadily decreases. To combat the depletion of the soil, the early farmers would use the so-called two-course system (also often referred to as the “two-field” system). They would divide arable land into two fields: one of the fields would be planted each year with cereal crops, while the other field would be allowed to lie fallow for a whole planting season (Isager & Skydsgaard, 1992). This would allow the fallow field to rest and regain its ability to grow cereals the next planting season. The two-course system was evidently used in agriculture since the early days of farming.

By the end of the 8th century CE it was already well known that the cultivation of legumes, such as beans, peas, oats, and lentils, enriches and restores the soil which ultimately results in an increased yield of cereal crops (Murphy, 2007, p. 123). This led to the emergence of the three-course rotation system, where arable land would be divided into three fields: cereal crops would be planted in the autumn on one of the three fields, legumes would be planted in the spring on the second field, while the third field would lie fallow. The following season, the crop assignments would rotate. Compared to the two-course system, in the three-course system only a third of the land lays fallow, which results in a considerable increase of productivity. In addition, the use of legumes positively affects the soil and further increases the yield. The three-course system was used in some areas of Europe as early as the 8th century (White, 1962, pp. 69-76). By the 13th century, it was already in widespread use in most parts of Europe (Hopcroft, 1999, p. 33).

This discussion doesn’t take any stances concerning the important question of distinctness of science and technology. There is a legitimate question on whether it is even justified to speak of any distinction between science and technology, or whether the two are to be conceived in unity. The notion of technoscience has been suggested to capture this unity (Latour, 1987; for discussion see Niiniluoto, 2016; Nordmann, 2016).
It is safe to say that European farmers of the 13-14th centuries had a good idea of the advantages of the three-course system over the two-course system. We have many surviving charters prescribing very precise divisions of arable land and indicating which crop is to be cultivated on which field in each given year as well as which field is to lie fallow. Importantly, many of these charters prescribed the three-course system, which is a direct evidence that the advantages of the three-course system were accepted (Fox, 1986, p. 528 and references therein). Yet, as with any other accepted theory, accepting the superiority of the three-course system over the two-course system didn’t necessarily result in using that system in practice. There were many factors that decided which system was actually used in each individual case, including “local customs and rules about the use, ownership, and inheritance of land and informal normative rules” (Hopcroft, 1999, p. 8). For instance, in some cases there was no incentive for farmers to invest in the land and increase the long-term production. In other cases, village regulations made switching from a two- to three-course system costly. Thus, while the advantages of the three-course system were very well known, its use in practice was in some cases hindered by specific local circumstances. This disparity suggests that accepting technological knowledge is not the same as using it in practice.

This straightforward example illustrates what has already been emphasized in the philosophy of technology literature – the idea that “technology, though it may apply science, is not the same as or entirely applied science” (Vincenti, 1990, p. 4), as it produces accepted knowledge of its own. In fact, much of technological knowledge “is not directly available from the sciences, since it often concerns extremely detailed behavior in very specific circumstances. This… knowledge is therefore often generated within technology, by the engineering sciences” (Franssen et al., 2015).

Unsurprisingly, technological propositions can be both descriptive and normative. Descriptive technological propositions can concern different aspects of the design, construction, and operation of an artifact. Consider such propositions as “CRISPR-Cas9 technology makes it possible to manipulate gene expression in plants, animals, and humans”, “Harrison’s fourth marine chronometer, H-4, is 13 cm in diameter”, “In the Windows 10 operating system, the combination of Alt+F4 closes the current window”. Similar to theories in science, these technological propositions attempt to describe something. The most profound difference, however, is that technological propositions describe artifacts as opposed to natural, social, or formal objects.

In addition to propositions that describe artifacts, technology also produces propositions that prescribe how artifacts ought to be properly operated (Winner, 1980). Consider, for instance, a set of instructions for a new lawnmower or blender, or a set of troubleshooting guidelines for a drone. Alternatively, consider the general norms of biomedical ethics (Beauchamp and Childress, 2009), launch commit criteria for space missions (National Aeronautics and Space Administration, 2014), or norms of ownership and privacy in information technology (Johnson, 2009; Quinn, 2012). In all these cases, we are dealing with norms that prescribe how certain actions ought to be performed, what is permissible, what is mandatory, etc.

What’s important for our discussion is that both descriptive and normative technological propositions can and often are accepted by epistemic agents. Regardless of whether a technological theory describes an artifact’s design, construction, and operation, or whether it prescribes a certain mode of its correct or recommended usage, it is safe to say that it can become accepted by an epistemic agent. Thus, it is my suggestion that we, as scientonomists, accept the existence of accepted technological theories to ensure that our position is in tune with that of the philosophy of technology community.
Are there Reasons to Think that Changes in Technological Knowledge Violate the Scientonomic Laws?

Once we accept that technological propositions are part of the ontology of scientific change, a question emerges as to whether their dynamics exhibits the same patterns of change as in formal, natural, and social sciences. At first sight, there appear to be at least three considerations potentially suggesting that changes in technological knowledge need not obey the accepted laws of scientific change. These are the argument from the distinctiveness of technological methods, the argument from normativity, and the argument from tacit knowledge. In this section, I will address each of these potential objections.

Some authors have argued for the distinctiveness of technological knowledge on the grounds that it is expected to satisfy the requirement of methods that are quite different from those employed in the sciences. Thus, according to Vincenti, “the 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… I would venture it more or less as follows: Does it help in understanding ‘some peculiar features of the universe’?” (Vincenti, 1990, p. 254). The idea here is that what characterizes a field of inquiry is its method(s) of theory evaluation. In this view, “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” (Houkes, 2009, p. 311). Because technology and science employ different methods of theory evaluation, so the argument goes, the two cannot possibly exhibit the same patterns of change. This is the gist of the argument from the distinctiveness of technological methods.

Even a cursory knowledge of scientonomy is sufficient to realize why this argument doesn’t hold water. If the mere distinctiveness of methods employed in two fields of inquiry were to give rise to two distinct patterns of change, then the whole scientonomic project would be doomed. Luckily, however, scientonomy is built on the idea that methods of theory evaluation differ not only across fields of inquiry but also across time. In addition, we know that even within the same science, there are often many different employed methods of theory evaluation, or different implementations of the same method. Consider for example, the methods of clinical epidemiology, where the requirements employed in evaluating the efficacy of drugs differ considerably from those employed in evaluating surgical techniques (Mercuri & Barseghyan, 2019). The laws of scientific change currently accepted in theoretical scientonomy explain exactly how these methods change through time, i.e. how they become employed, how they become rejected, and how this process is affected by the acceptance and rejection of theories. What’s important here is that, to the best of our scientonomic knowledge, changes in methods employed in diverse fields of inquiry exhibit the exact same patterns, regardless of the specific content of these methods. Thus, even if it were true that the methods of theory evaluation employed in technology were very different from those employed in the sciences, there would still be no obvious reason why that would result in patterns of change different from those we locate in other fields of inquiry. This sidesteps the argument from the distinctiveness of technological methods.

Several authors have appealed to the normative nature of technological propositions to highlight the difference between scientific and technological knowledge. Thus, Simon argues that “the natural sciences are concerned with how things are… Design, on the other hand, is concerned with how things ought to be, with devising artifacts to attain goals” (Simon, 1969, p. 114; see also Simon, 1996, pp. 4-5). According to Hendricks et al., this is because “the modal mood of a pure scientist is largely descriptive, while the mood of engineering is generally prescriptive” (Hendricks et al., 2000, p. 278). Lee concurs: “To emphasize the distinction between scientific and technological knowledge, one may say that while the former attempts to formulate laws (about universal regularities), the latter aims at establishing rules. Laws are descriptive – when conditions x, y, z obtain, A obtains. Rules, on the other hand, are prescriptive. They are hypothetical imperatives – if one wishes to achieve A, then one ought to do x” (Lee, 2009, 33).

The question of what methods have been employed in diverse fields of technology at different time periods and how similar these methods were to the respective methods in physics, chemistry, biology, or sociology is of great interest to observational scientonomy. Yet, it does not affect our current discussion.
Importantly, the champions of this view do not necessarily deny that many technological propositions are
descriptive, but rather see one key difference between science and technology in the fact that the latter involves
*not only* descriptive propositions but also normative propositions, such as “a properly functioning photocopier
ought to enable us to make a duplicate of the text on a sheet of paper”. According to de Vries, “this normative
dimension makes technological knowledge different from scientific knowledge. Scientific knowledge does not
have this "ought to" aspect” (De Vries, 2006, 27). This is the gist of the argument from normativity (see also,
Franssen, 2009).

It is easy to see that this argument too misses its target. Let us suppose, for the sake of argument, that producing
guidelines on how things ought to be is not the main goal of science. Yet, even if that were so, it wouldn’t
necessarily mean that while aiming at increasingly correct descriptions of their respective objects, physics,
biology, or sociology do not also make normative claims (Houkes, 2009, p. 338). Among other things, accepted
*methodological* dicta are a good example of normative propositions produced by science. For instance, clinical
epidemiologists do not just test the efficacy of different treatments and rehabilitation techniques, but also propose
and accept methodological guidelines on how such testing ought to be conducted. For example, both the United
States Food and Drug Administration (USFDA) and Health Canada accept the guidelines developed within the
Expert Working Group (Efficacy) of the International Conference on Harmonisation of Technical Requirements
for Registration of Pharmaceuticals for Human Use (U.S. Food and Drug Administration, 2001; Health Canada,
2011). These guidelines include a great number of normative propositions concerning different aspects of
randomized controlled trials.

Crucially, current theoretical scientonomy explains changes in both descriptive and normative propositions.
Thus, the second law (Patton, Overgaard, & Barseghyan, 2017) concerns not only the acceptance of descriptive
theories, but also the acceptance of normative theories. Therefore, the mere fact that technological knowledge
includes normative propositions doesn’t exclude it from the domain of the laws of scientific change. As the current
laws apply to both descriptive and normative propositions, it is not at all clear why technological knowledge
should be an exception. In short, the argument from normativity doesn’t seem to hold much water.

Finally, it might be tempting to think that changes in technological knowledge could be somehow exempt
from the laws of scientific change due to the fact that at least some parts of technological knowledge are *tacit*. According to an idea famously championed by Karl Polanyi, tacit knowledge is the central feature of technology
(Polanyi, 1958; 1966). This point has been repeated in different forms by many authors. Consider, for instance,
Rosenberg’s claim that technology is itself a body of “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). This becomes particularly evident when technological knowledge is being transmitted from one agent to
another. Arora notes that such a transfer “requires that tacit knowledge be transferred alongside the more formal
and codified parts of technology” (Arora, 1996, p. 234).

It’s clear that there is more to *technological knowledge* than propositions carefully articulated in technological
manuals. But it is not at all obvious how the tacit nature of parts of technological knowledge can possibly make
the current scientonomic laws inapplicable to changes in it. To tackle the argument from tacit knowledge, I will
make use of a three-fold distinction that Hakob Barseghyan and I have recently suggested in our attempt to clarify
the notion of *tacit knowledge* (Barseghyan & Mirkin, 2019). Most importantly the traditional category of *tacit*
knowledge includes both the knowledge that has not yet been explicated by an epistemic agent, but *can in principle be explicated* propositionally, and knowledge that is *inexplicable even in principle*. To avoid confusion,
we have suggested a new three-fold distinction that clearly delineates between knowledge that is *not yet explicated*
and knowledge that is inexplicable *in principle*:
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It is true that in many technologies there is a vast layer of implicit know-how. It is also possible that some of this implicit knowledge is inexplicable as a set of propositions. Yet, what’s important for our purposes is the fact that at least some of this implicit know-how can be expressed propositionally. When John Harrison and his 18th-century colleagues were constructing the first precise marine chronometers for finding longitude at sea, they mostly relied on their own implicit know-how (Sobel, 1998). It is a historical fact, however, that this knowledge has been propositionally described, specifically in the 20th century by Rupert Thomas Gould (Gould, 2013). The new three-fold distinction that we have suggested aims to capture precisely this difference between explicable-implicit and inexplicable as two subtypes of tacit knowledge. In addition, the distinction helps demarcate propositional from non-propositional knowledge; while inexplicable knowledge is non-propositional, explicit and explicable-implicit are two sub-types of propositional knowledge. Here is how the traditional dichotomies map on our three-fold distinction (Barseghyan & Mirkin, 2019):

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The current scienonomic definition of theory as a set of propositions (Sebastien, 2016) suggests that we should focus on propositional technological knowledge – both explicit and explicable-implicit. As for non-propositional knowledge, we will put this category aside for now, since scienonomy doesn’t seem to be equipped to tackle that notion just yet due to its specific notion of theory. Besides, the very existence of inexplicable knowledge is a matter of debate between intellectualists and anti-intellectualists (Ryle, 1949; Stanley & Williamson, 2001; Stanley, 2011; Fantl, 2017). At this point, I will refrain from taking any stances on the existence of inexplicable (non-propositional) knowledge. What is clear is that at least part of tacit technological knowledge is explicable and that is more than sufficient for our current purposes.

If we apply this three-fold distinction, we find examples of explicable-implicit knowledge in most sciences. According to Barseghyan, most sciences involve not only explicitly stated propositions, but also assumptions which can remain implicit for decades or even centuries (Barseghyan, 2018, p. 27). As an example, he mentions...
the famous idea that, objectively, particles always have well-defined positions and velocities even before these positions and velocities are measured. This idea was accepted implicitly as part of classical physics for a long time until it was finally explicated by Einstein (Barseghyan, 2018, p. 27; Fine, 2017). He also mentions the tacit assumption concerning the possibility of arbitrarily large velocities – an assumption, accepted by physicists for a few centuries prior to its explication and rejection as a result of the acceptance of relativity theory (Barseghyan, 2018, p. 27; Goldhaber, 1975).

Now, it is currently accepted in scientonomy that this explicable-implicit layer of knowledge plays the same role that explicit knowledge does in its influence on the patterns of scientific change. The laws of scientific change apply to all mosaic elements, regardless of whether they are explicitly stated or implicitly assumed. No doubt, we might be wrong in this, but as long as we accept that the patterns of scientific change apply to both explicit and implicit propositional knowledge, I don’t see how we can possibly think that a similar layer of explicable-implicit technological knowledge can somehow render the scientonomic laws inapplicable to technological knowledge. This voids the argument from tacit knowledge.

The discussion in this section shows that there don’t seem to be any prima facie considerations for thinking that technological propositions should somehow exhibit patterns different from those exhibited in other fields of inquiry. In the remainder of this essay, I will present some positive evidence suggesting that changes in technological knowledge exhibit the same patterns of change as for scientific knowledge.

Are there Reasons to Think that Scientific and Technological Knowledge Exhibit the Same Patterns of Change?

Showing that theory and method changes occurring within a whole field of inquiry exhibit certain general patterns is not a task that can be accomplished within a single paper. Therefore, my current task is more modest – to show that there is some evidence suggesting that technological knowledge exhibits the same patterns of change as other fields of inquiry. This shouldn’t come as a surprise since, as we have seen, technological theories involve both descriptive and/or normative propositions that attempt to describe and/or prescribe the design, construction, or operation of artifacts. Here, I will discuss a few cases that illustrate how technological knowledge – both descriptive and normative – seems to exhibit the usual scientonomic patterns.

Consider first the case of sorting algorithms from information technology. To sort numbers, a programmer requires a different algorithm based on the size of the list and requirements of the program. These algorithms can be used for a number of general purposes. There are multiple types of sorting, which include an insertion sort, selection sort, quicksort, merge sort, etc. As different sorting algorithms have different properties, computer programmers customarily evaluate the efficiency of these various algorithms. How do they do that? When evaluating the efficiency of a sorting algorithm, computer programmers look at a variety of different criteria, including the algorithm’s time complexity and space complexity.

Time complexity estimates how much time it takes for a computer to complete its run of a sorting algorithm given the size of the list of data to be sorted (Sipser, 2006, p. 248). An algorithm is said to take quadratic time, if its time of execution is proportional to the square of the input data set size. In contrast, an algorithm is said to be linear, if its time of execution increases linearly with the size of the input. The algorithm’s worst-case time complexity estimates the maximum time it takes for an algorithm to sort inputs of a given size. The algorithm’s worst-case complexity is not to be confused with its best-case time complexity which estimates the time taken by the algorithm under optimal conditions. Finally, the algorithm’s average-case time complexity measures the average time taken by the algorithm to sort a data set of a given size. In most cases, it is the worst-case time complexity that is taken as one of the criteria for evaluating the efficiency of sorting algorithms. There are some computing applications, such as control of an industrial process or of an automated device, where time is of the essence. In such real-time computing it is essential to ensure that the sorting algorithm always completes on time (Sipser, 2006, pp. 247-302).

Space complexity estimates how much space the sorting algorithm needs in the computer’s memory during its deployment. Similar to time complexity, space complexity is a function of the size of the input data set, i.e. it
estimates how much memory is required by the algorithm given a certain input size. Once again, computer
programmers seem to be concerned primarily with the algorithm’s worst-case space complexity. This is due to
the practical need to ensure that the space needs of the algorithm do not exceed the available memory of the
computer being used (Sipser, 2006, pp. 303–334).

These and other similar criteria are often employed to evaluate different sorting algorithms. For instance, it is
nowadays accepted that selection sort has quadratic worst-case complexity, i.e., its running time increases as a
square of the input size (Cormen, 2013, pp. 34–35). The same also holds for insertion sort (Cormen, 2013, pp. 38-
39). These criteria are also employed to compare the relative efficiency of different algorithms. Computer
programmers customarily speak of algorithm A having better worst-case time-complexity than algorithm B, or
algorithm C being more efficient on smaller data sets, while algorithm D being more efficient on larger data sets.
For instance, it is accepted that merge sort has a better worst-case time complexity than insertion sort (Cormen,
2013, p. 40). It is also accepted that quicksort’s average-case time complexity is better than that of selection sort
(Cormen, 2013, p. 49). Finally, it is accepted that in terms of worst-case space complexity merge sort is not as
efficient as either insertion sort or selection sort (Cormen, 2013, p. 40). Thus, computer programmers clearly
accept propositions describing relative efficiency of sorting algorithms, as indicated by the customarily inclusion
of these propositions in computer science textbooks as well as their extensive use in practice.

What is important from the scientonomic perspective is that these propositions are accepted because they
satisfy the algorithm comparison method employed by computer scientists. This is in full accord with the second
law of scientific change, which states that if a theory satisfies the acceptance criteria of the method employed at
the time, it becomes accepted into the mosaic (Patton, Overgaard, & Barseghyan, 2017). While reconstructing the
exact details of their algorithm comparison method is a task for a separate observational study, it seems clear that
in general they consider algorithms with quadratic complexity as less efficient than those with linear complexity.
Similarly, an algorithm that takes less space is considered more efficient in terms of space complexity. Once
again, the details of the method for evaluating different propositions about the efficiency of sorting algorithms
are yet to be explicated; that’s an interesting task for observational scientonomy. The key point here is that we are
clearly dealing with an epistemic agent that evaluates certain propositions – in this case, propositions about the
efficiency of sorting algorithms – by means of certain criteria and accepts these propositions when they meet
these criteria.

It is also important to note that, when accepted, technological theories often affect our methods of evaluating
scientific theories. The history of science provides great many examples of this phenomenon. Specifically, as
Hakob Barseghyan and I have recently shown, the acceptance of the trustworthiness of the telescope led to drastic
changes in the method of evaluation of astronomical data (Barseghyan & Mirkin, 2019). If we were to reconstruct
the criteria employed by astronomers in evaluating astronomical data prior to the invention of the telescope, they
would probably include a tacit clause that astronomical data should be obtained only in naked-eye observations:

![Dashed Box with Astronomical Data Acceptability](https://example.com/dashed-box-astronomical-data-acceptability)

This requirement was an implicit part of the method of evaluation of astronomical data employed up until the
times of Tycho Brahe in the late 16th century, when astronomers would rely exclusively on naked-eye observations
(Thoren, 1989). It took the newly invented telescope some time to become considered a trustworthy instrument
for astronomical observations (Goehring, 1978; Muir, 2007; van Helden, 1989; van Helden, 1994). Once it
became clear that the telescope can make distant astronomical objects appear larger and faint objects appear
brighter, the trustworthiness of the telescope became accepted, and it led to changes in the astronomers’ criteria
of evaluation of astronomical data – the acceptability of data obtained by a telescope became part of astronomers’
method:

- Astronomical data is acceptable only if it is obtained in naked-eye observations.
This transition was in full accord with the *third law* of scientific change (Sebastien, 2016): the new method was a deductive consequence of the community’s accepted theory concerning the trustworthiness of the telescope. Importantly, it was an accepted *technological* proposition that shaped the astronomers’ employed method in full accord with the third law of scientific change:

The case is similar to the employment of new cell counting methods discussed by Barseghyan in *The Laws of Scientific Change*. As new cell counting techniques emerge and as their trustworthiness becomes accepted by the community, it results in changes in cell counting methods (Barseghyan, 2015, pp. 151-152). Both the case of cell counting methods and the case of telescopic observation methods illustrate a simple idea: accepted technological knowledge shapes our methods of evaluation of scientific propositions in accord with the third law of scientific change.

Now that we have seen that technological theories can shape scientific methods, a question arises: can accepted *scientific* theories shape *technological* methods? The answer is “yes”. The field of medicine alone provides a plethora of cases where accepted scientific theories affect medical technology.

Consider, for example, how the accepted theories of carcinogenesis have shaped surgeons’ stance towards the effectiveness of the surgical treatment of colorectal cancer. For a long time, most surgeons and physicians believed that treatments of colorectal cancer cannot be effective. While some cancers were believed to be curable at their commencement, most tumors were thought to be inoperable. This view on inapplicability of surgical treatment to developed forms of cancer was accepted by most medical communities since antiquity and up until the late 19th century and was a deductive consequence of the accepted views on carcinogenesis (Ballantyne, 1988, pp. 513-514).

According to Galen’s *humoral theory* of carcinogenesis accepted by many communities of physicians and surgeons well into the 17th century, a tumor is the result of an imbalance of the bodily humors. Specifically, a cancerous tumor is due to the accumulation of black bile in one location. The tumor, therefore, is only a part of the issue; more importantly, it indicates an underlying disease of the whole tissue, organ, or even the whole body (Olszewski, 2010, pp. 183-184). Therefore, according to the humoral theory, a mere surgical removal of the tumor cannot cure the disease, since the disease is due to an imbalance of the humors. Because of this understanding of the origins of cancer, Galenic communities accepted that cancer is mostly inoperable (Ballantyne, 1988, pp. 513-514).

A belief in the inoperability of most cancers was also implicit in the *lymph theory* of Descartes, Stahl, Hoffman, and Hunter. In many communities, this theory replaced Galen’s humoral theory in the 17-18th centuries and remained accepted until the end of the 19th century (Wagener, 2009, pp. 19-23). According to the lymph theory, while tumors originate locally, the disease is then quickly transported to lymph nodes and spreads throughout the body by the lymphatic system (Olszewski, 2010, p. 184). Thus, the tumor can be successfully removed, and the spread of the disease can be prevented only if it is caught early. Yet, in most cases, tumors
manifest themselves only when the disease is already spread throughout the body. That is why, according to the champions of the lymph theory, the surgical treatment of cancer is generally ineffective (Ballantyne, 1988, p. 514).

In brief, it was implicit in both the humoral theory and the lymph theory that cancer is not merely a localized lesion but is a disease spread throughout the body, which makes it generally inoperable. Surgical treatment was considered reasonable only in those cases when a large part of the tissue surrounding the tumor could also be easily removed (Ballantyne, 1988, p. 514). This applied to most types of superficial cancers, such as skin or breast tumors. Yet, the idea of surgically excising deeper tumors, such as those within the abdomen, was questionable as the removal of large areas of surrounding tissue was extremely problematic. Consequently, surgical treatment of colorectal cancer was thought to be destined to fail.

In practice, this often resulted in the refusal to perform surgical removal of colorectal cancers even when the surgical techniques themselves were available. A number of techniques for operating on colorectal cancer were proposed in the 18-19th centuries and several surgeons even attempted resections of colorectal cancer in practice (Tebala, 2015, pp. 737-744). However, since at the time the accepted view was that cancer is not a local disease, it was also generally accepted that local surgical excisions of colorectal tumors cannot be an effective cure for the underlying disease (Ballantyne, 1988, p. 515).

From the scientonomic point of view, what we have here is a case of accepted scientific knowledge shaping the method of evaluation of the effectiveness of a certain technique. Indeed, it was only natural for a medical community that accepted a non-local etiology of most cancers not to have high hopes concerning local surgical techniques of their removal. Thus, the method of evaluation of cancer treatments employed by these communities can be explicacted along these lines:

A cancer treatment can be effective only if it takes into account the non-local nature of the disease and treats not only the tumor itself but also the surrounding tissue/organ.

How exactly this abstract requirement was implemented in different medical communities is an interesting question for observational scientonomy, but it doesn’t concern us here. What is important for our purposes is the very phenomenon of an accepted scientific theory – in this case, the idea of cancer’s non-local etiology – shaping the method employed in evaluating technological theories – in this case, claims about the effectiveness of different cancer treatment techniques. Once again, we see how our accepted theories shape our employed methods in full accord with the third law, only in this case it is an accepted scientific theory that shapes a method for evaluating claims about the effectiveness of techniques in a certain domain:

<table>
<thead>
<tr>
<th>Theory</th>
<th>Method</th>
</tr>
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<tbody>
<tr>
<td>Cancer is a non-local disease that affects the whole surrounding tissue, organ, or perhaps even the whole body.</td>
<td>A cancer treatment can be effective only if it takes into account the non-local nature of the disease and treats not only the tumor itself but also the surrounding tissue/organ.</td>
</tr>
</tbody>
</table>

Accepted scientific theories... ...shapes the method employed in evaluating technological theories.
What these three cases – the case of sorting algorithms, the case of telescopic observations, and the case of surgical treatments of colorectal cancer – all illustrate is that there are accepted technological theories and employed technological methods. In addition, the two latter examples show that technological theories shape scientific methods and scientific theories shape technological methods according to the third law of scientific change.

**Conclusion**

We have both theoretical and historical reasons to believe that propositional technological knowledge can be and often has been part of an epistemic agent’s mosaic. First, from the perspective of its propositional content, technological knowledge doesn’t seem to be different in kind from theories in natural, social, and formal sciences. Both explicit and explicable-implicit technological theories attempt to describe the construction and operation of artifacts as well as prescribe their mode of operation. The history of technology also shows that technological theories are not merely used but also often accepted by epistemic agents. What is also clear is that accepted technological theories often shape methods employed in evaluating scientific theories. The opposite is also often the case: accepted scientific theories often shape methods employed in evaluating technological theories. In both cases, the shaping seems to take place in full accord with the third law of scientific change.

Clearly, more work needs to be done to ascertain that the dynamics of technological knowledge exhibits the exact same patterns as those in natural, social, and formal sciences. That would require a much more comprehensive treatment of the history of both science and technology. What this preliminary discussion helps to clarify is that we currently have no obvious reason to suspect that changes in technological knowledge should somehow exhibit patterns different from those exhibited by the process of scientific change. This conclusion is supported by a theoretical argument from the nature of propositional technological knowledge as well as illustrated by a few examples from diverse fields of technology. While my preliminary discussion of these examples is no substitute for a proper comprehensive historical study, it nevertheless suggests that changes in accepted technological theories and employed methods of their evaluation seem to be amenable to a scientonomic interpretation in terms of the laws of scientific change. Thus, I suggest we accept that, to the best of our knowledge, changes in technological knowledge exhibit the same patterns of change as changes in scientific knowledge until shown otherwise. In the absence of serious reasons to suspect that it should be otherwise, such a course of action seems to be completely reasonable.

Once we accept that propositional technological knowledge is a part of the process of scientific change, we will be able to pose and tackle an important observational question: what technological theories were accepted and what technological methods were employed by different epistemic agents at different time periods? In addition, there will be an important theoretical question concerning the status of inexplicable knowledge: is there such a thing as inexplicable knowledge – technological or otherwise – and, if so, how does it change through time? Another important theoretical question concerns the typology of technological knowledge: what types of knowledge does technology produce?

**Acknowledgments**

I would like to thank Hakob Barseghyan, Paul Patton, and Gregory Rupik for their input in the development of the ideas presented in this essay.
Suggested Modifications

Thus, I suggest the following modifications:

**[Sciento-2018-0011]**

Accept the three-fold distinction between *explicit*, *explicable-implicit*, and *inexplicable* with the following definitions:

- *Explicit* ≡ propositional knowledge that has been openly formulated by the agent.
- *Explicable-Implicit* ≡ propositional knowledge that hasn’t been openly formulated by the agent.
- *Inexplicable* ≡ non-propositional knowledge, i.e. knowledge that cannot, even in principle, be formulated as a set of propositions.

<table>
<thead>
<tr>
<th>Can it be, in principle, formulated as a set of propositions?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Has it been openly formulated by the agent?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Inexplicable</strong>: Non-propositional knowledge, i.e. knowledge that cannot, even in principle, be formulated as a set of propositions.</td>
<td></td>
</tr>
</tbody>
</table>

Also accept the following definition of *implicit*:

- *Implicit* ≡ not explicit.

**[Sciento-2018-0012]**

Accept that propositional technological knowledge – i.e. technological questions, theories, and methods – can be part of a mosaic.

Also accept the following questions as legitimate topics of scientonomic inquiry:

- *History of Technological Mosaics*: What technological theories were accepted and what technological methods were employed by different epistemic agents at different time periods?
- *The Status of Inexplicable Knowledge*: Is there such a thing as inexplicable knowledge?
- *Typology of Technological Knowledge*: What types of technological knowledge are there?

References


