Chapter 2
Science and Technology: What They Are and Why Their Relation Matters

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Abstract The relationship(s) between science and technology can be conceived in different ways depending on how each of the two concepts is defined. This chapter traces them both back to the medieval tradition of knowledge classification and its notions of science and mechanical arts. Science can be defined either in the limited sense of the English language or in a broader sense that includes the humanities. It is argued that the latter approach provides a more adequate delimitation from an epistemological point of view. The word "technology" can refer either to knowledge about practical activities with tools and machines (a common sense in German and many other languages) or to these activities, tools, and machines themselves (the common sense of the word in English). Based on conceptual clarifications of the two concepts, four classes of philosophically interesting questions about science-technology relationships are outlined: (1) the relation between science in general and technological science, (2) the role of science in technological practice, (3) the role of technological practice in science, and (4) the relationship between science and the Aristotelian notion of productive arts (that is more general than the notion of technological practice).

1 Introduction

Before delving into the relationship(s) between science and technology we should pay some attention to the meanings of each of these two terms. Do they represent important and well-demarcated concepts, or are they delimited in unsystematic ways that make them unsuitable as objects of philosophical reflection? We will begin by tracing their origins in the classifications of knowledge that had a prominent role in academic treatises from the Middle Ages and well into the modern age. Section 2 introduces the medieval tradition of knowledge classification, and Sect. 3 the place of what we now call technology in these classifications systems. Sections 4 and 5 discuss the origins and the vagaries of the terms "science" respectively

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"technology". In Sect. 6 it is suggested that attention to the different meanings of the two terms can help us to distinguish in a more precise way between different approaches to what we call the "science – technology relationship".

2 Knowledge Classification

The classification of areas of human knowledge was a recurrent theme in learned expositions throughout the Middle Ages. A large number of classification schemes have survived, usually with a tree-like structure that organized the various disciplines in groups and subgroups. These classification schemes[1] served to identify the areas worthy of scholarly efforts, and often also to list the disciplines to be included in curricula (Dyer 2007; Ovitt 1983). But despite the great care that was taken in listing and categorizing the different branches of knowledge, not much importance seems to have been attached to the choice of a general term to cover all knowledge. "Scientia" (science), "philosophia" (philosophy), and "ars" (arts) were all used for that purpose.

Etymologically, one might expect a clear distinction between the three terms. "Scientia" is derived from the verb "scire" (to know) that was used primarily about knowledge of facts. "Philosophia" is a Greek term that literally means "love of wisdom", but it was often interpreted as systematic knowledge and understanding in general, both about facts and about more speculative topics such as existence and morality. Cicero influentially defined it as follows:

> [P]hilosophy is nothing else, if one will translate the word into our idiom, than 'the love of wisdom'. Wisdom, moreover, as the word has been defined by the philosophers of old, is 'the knowledge of things human and divine and of the causes by which those things are controlled.'[2] (Cicero, *De Officiis* 2.5)

"Ars" refers to skills, abilities, and craftsmanship. It was the standard translation of the Greek "techne". Aristotle provided an influential and ingenious definition of the concept that has often been referred to as a definition of the productive arts:

> Now since architecture is an art and is essentially a reasoned state of capacity to make, and there is neither any art that is not such a state nor any such state that is not an art, art is identical with a state of capacity to make, involving a true course of reasoning. All art is concerned with coming into being, i.e. with contriving and considering how something may come into being which is capable of either being or not being, and whose origin is in the maker and not in the thing made; for art is concerned neither with things that are, or come into being, by necessity, nor with things that do so in accordance with nature (since these have their origin in themselves). (Aristotle, *Nichomachean Ethics* VI:4)

[1] *Divisiones scientiarum* or *divisiones philosophiae*.

[2] [N]ec quicquam aliud est philosophia, si interpretari velis, praeter studium sapientiae. Sapientia autem est, ut a veteribus philosophis definitum est, rerum divinarum et humanarum causarumque, quibus eae res continentur, scientia.

But in spite of their differences in meaning, all three terms were used interchangeably as umbrella terms for all knowledge. The usage differed between authors in what seems to be a very unsystematic way. Some authors used "science" as the most general term and "philosophy" as a second-level term to denote some broad category of knowledge disciplines. Others did exactly the other way around, and still others used "science" and "philosophy" as synonyms. Similarly, "art" was sometimes used to cover all the disciplines, sometimes to cover some broad subcategory of them. This terminological confusion persisted well into the sixteenth and seventeenth centuries (Covington 2005; Freedman 1994; Ovitt 1983). For a modern reader it may be particularly surprising to find that in the Middle Ages, "philosophy" included all kinds of knowledge, also practical craftsmanship. From the end of the fifteenth century it became common to exclude the crafts (the mechanical arts) from philosophy, but as late as in the eighteenth century the word "philosophy" was commonly used to denote all kinds of knowledge (Freedman 1994; Tonelli 1975).

3 The Mechanical Arts

In medieval and early modern times, the term "art" (ars) referred to all kinds of skills and abilities. It did not suggest a connection with what we today call the "fine arts" or just "art". The notion of art included "not only the works of artists but also those of artisans and scholars" (Tatarkiewicz 1963, 231).[3] The arts emphasized in knowledge classifications were the so-called "liberal arts". This is a term used since classical antiquity for the non-religious disciplines usually taught in schools, so called since they were the arts suitable for free men (Chenu 1940; Tatarkiewicz 1963, 233). Medieval universities had four faculties: Theology, Law, Medicine, and the Arts. The former three were the higher faculties to which a student could only be admitted after studying the liberal arts at the Faculty of Arts (also called the Faculty of Philosophy) (Kibre 1984).

Since the early Middle Ages, the liberal arts were usually considered to be seven in number, and divided into two groups. A group of three, called the "trivium" consisted of what we may call the "language-related" disciplines, namely logic, rhetoric, and grammar. The other group, the "quadrivium", consisted of four mathematics-related subjects, namely arithmetic, geometry, astronomy, and

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

music. By music was meant a theoretical doctrine of harmony that had more in common with mathematics than with musicianship (Dyer 2007; Freedman 1994; Hoppe 2011; James 1995). Various authors made additions to the list of liberal arts, claiming that one or other additional activity should be counted as a liberal art. Not surprisingly, Vitruvius saw architecture as a liberal art, and Galen wanted to add medicine to the list. Others wanted to give agriculture that status, probably due to its association with a simple, innocent life (Van Den Hoven 1996).

The liberal arts explicitly excluded most of the activities undertaken for a living by the lower and middle classes. In antiquity such arts were called illiberal, vulgar, sordid, or banausic.[4] These were all derogative terms, indicating the inferior social status of these activities and reflecting a contemptuous view of physical work that was predominant in classical Greece (Van Den Hoven 1996, 90–91; Ovitt 1983; Tatarkiewicz 1963; Whitney 1990). In the Middle Ages, the most common term was "mechanical arts".[5] It was introduced in the ninth century by Johannes Scotus Eriugena in his commentary on Martianus Capella's allegorical text on the liberal arts, *On the Marriage of Philology and Mercury*.[6] According to Johannes Scotus, Mercury gave the seven liberal arts to his bride, Philology, and in exchange she gave him the seven mechanical arts. However, Scotus did not name the mechanical arts (Van Den Hoven 1996; Whitney 1990). Instead a list of seven mechanical arts, or rather groups of arts, was provided in the late 1120s by Hugh of Saint Victor:

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

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

The distinction between liberal and mechanical arts continued to be used in the early modern era, and it had an important role in the great French *Encyclopédie*, published from 1751 to 1772, that was the most influential literary output of the Enlightenment. One of its achievements was the incorporation of the mechanical

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

[5] Artes mechanicae.

[6] De nuptiis Philologiae et Mercurii.

arts, i.e. what we call technology, into the edifice of learning. In the preface Jean Le Rond d'Alembert (1717–1783) emphasized that the mechanical arts were no less worthy pursuits than the liberal ones.

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

4 The Modern Term "Science"

The English word "science" derives from the Latin "scientia", and originally, it had an equally wide meaning. It could refer to almost anything that you had to learn in order to master it: everything from scholarly learning to sewing and horse riding. But in the seventeenth and eighteenth centuries the meaning of "science" was restricted to systematic knowledge. The word could for instance refer to the knowledge you need to make a living in a particular practical trade. In the nineteenth century the meaning of "science" was further restricted, and it essentially meant what we would today call natural science (Layton 1976). Today, the term "science" is still primarily used about the natural sciences and other fields of research that are considered to be similar to them. Hence, political economy and sociology are counted as sciences, whereas literature and history are usually not. In several academic areas considerable efforts have been devoted to making one's own discipline accepted as a science. This applies for instance to social anthropology that is often counted as a science although it is in many respects closer to the humanities (Salmon 2003).

Thus, given the current meaning of the term, far from all knowledge can be described as scientific. However, the distinction between scientific and non-scientific knowledge depends not only on epistemological principles but also on historical contingencies. This we can see clearly from the difference in meaning between the word "science" in English and the corresponding word "Wissenschaft" in German with its close analogues in Dutch and the Nordic languages. "Wissenschaft" also originally meant knowledge, but it has a much broader meaning than "science". It includes all the academic specialties, including the humanities. With its wider area of application, "Wissenschaft" is closer than "science" to "scientia".

In my view, the German term "Wissenschaft" has the advantage of giving a more adequate delimitation from an epistemological point of view than the English term. "Wissenschaft" does not exclude academic or otherwise systematized

knowledge disciplines such as history and other humanities that are excluded from the "sciences" due to linguistic conventions. The restricted sense of the English word "science" is unfortunate since the sciences and the humanities share a common ground, in at least two respects. First, their very raison d'être is the same, namely to provide us with the most epistemically warranted statements that can be made, at the time being, on the subject matter within their respective domains.

Secondly, they are intricately connected, and together they form a *community of knowledge disciplines* that is characterized and set apart by mutual respect for each other's results and methods (Hansson 2007b). Such mutual respect is something that we take for granted for instance between physics and chemistry, but it also holds across the (contrived) boundary between the sciences and the humanities. An archaeologist or historian will have to accept the outcome of a state-of-the art chemical analysis of an archaeological artefact. In the same way, a zoologist will have to accept the historians' judgments of the reliability of an ancient text describing extinct animals. In order to understand ancient descriptions of diseases we need co-operations between classical scholars and medical scientists (and most certainly not between classical scholars and homeopaths or between medical scientists and bibliomancers).

Neither "science" nor any other established term in the English language covers all the members of this community of knowledge disciplines. For lack of a better term, I will call them "science(s) in a broad sense". The name is not important, but it is important to recognize that we have a community of knowledge disciplines that all strive to obtain reliable knowledge and all respect the other disciplines in their respective areas of speciality. Many discussions on science (such as that about the science–pseudoscience distinction) seem to refer in practice to science in the broad sense, but that is not always made as clear as it should be (Hansson 2013b).

Science, in this broad sense, is an epistemological, not a sociological category. The knowledge disciplines belonging to science in the broad sense are characterized by a common aim, namely to provide us with the most epistemically warranted information that can be obtained in subject-matter within their respective domains. This definition is close to coinciding with the academic disciplines, but it does not coincide exactly with them. There are some (minor) branches of learning that satisfy the inclusion criteria but do not have academic status. This applies for instance to philately and to the history of conjuring, both of which are pursued by devoted amateurs rather than by professional scholars.

5 The Modern Term "Technology"

The word "technology" is of Greek origin, based on "techne" that means art or skill and "-logy" that means "knowledge of" or "discipline of". The word was introduced into Latin as a loanword by Cicero (Steele 1900, 389).[7] However, it

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

does not seem to have been much used until Peter Ramus (1515–1572) started to use it in the sense of knowledge about the relations among all technai (arts). The word became used increasingly to denote knowledge about the arts. In 1829 the American physician and scientist Jacob Bigelow published *Elements of Technology* where he defined technology as "the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science" (Tulley 2008). Already in the late seventeenth century "technology" often referred specifically to the mechanical arts and the skills of craftspeople (Sebestik 1983). This sense became more and more dominant, and in 1909 *Webster's Second New International Dictionary* defined technology as "the science or systematic knowledge of industrial arts, especially of the more important manufactures, as spinning, weaving, metallurgy, etc." (Tulley 2008). This means that technology was no longer conceived as knowledge about *techne* in the original Greek sense of the term, i.e. arts and skills in general. It had acquired a more limited sense referring to what is done with tools and machines.

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

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

6 Interrelations Between Science and Technology

Given all these meanings of "science" and "technology", we can mean different things when discussing the relationship between science and technology. As to science, the crucial difference is that between the restricted sense of the word in modern English and the broader sense attached both to its Latin ancestor "scientia" and to the corresponding words in German and several other languages. From an epistemological point of view, the broader sense is more interesting since, as I noted above, it represents a more principled, less arbitrary demarcation. From a sociological point of view, on the other hand, there may be good reasons to focus on "science" in the conventional English sense of the word. Arguably science (in this sense) has a social identity or role not shared by the humanities; not least in relation to engineering and technology (in at least some senses of the latter word).

Turning to technology, there are even more options. First of all, we must distinguish between technology as systematic knowledge about practices involving tools, machines etc., and technology as these practices themselves. We can call the first of these technology-knowledge and the second technology-practice.[8] The relationship between technology-knowledge and science would seem to be one of subsumption rather than conflict. In other words, technology-knowledge is a branch of science rather than something that runs into conflict with science. But as already mentioned, this is not the common sense of "technology" in English. To refer to this concept in English it is probably best to use the phrase "technological science".

Technology-practice is a subclass of the "productive arts" in the Aristotelian sense, since it is concerned with the creation of something new. It consists mainly of those productive arts that produce material things with the help of tools or machines. There are also other productive arts that we do not usually call "technology", such as the arts of medicine, farming, music, dance, etc. We seldom use the phrase "productive arts" today, but that does not make the category philosophically uninteresting. It is reasonable to ask whether some of the philosophical issues that we discuss in relation to technology can be generalized in an interesting way to the productive arts.

Some of these distinctions are summarized in Fig. 2.1. The left circle represents technological science (technology-knowledge), whereas the right circle represents the most common meaning of "technology" in English, namely technology-practice. The ellipse surrounding technological science represents the wider category of science in general (taken here preferably in the broad sense), whereas that surrounding technology-practice represents the useful but today largely obliviated Aristotelian concept of the productive arts. Given these conceptual clarifications, there are at least four classes of interesting philosophical problems about the relationships between science and technology. They are schematically represented in Fig. 2.2.

[8] Or techno*logy* and *techno*logy.

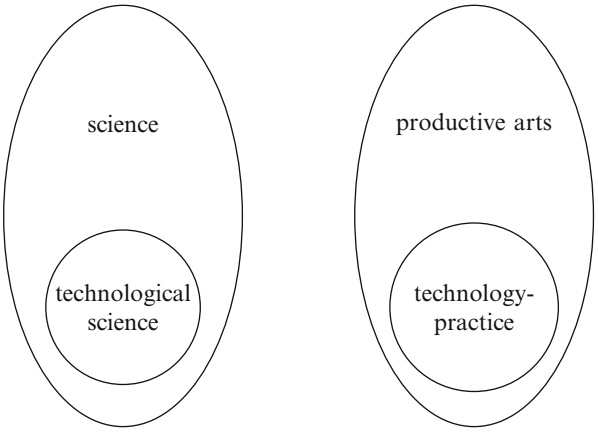

Fig. 2.1 Two major meanings of "technology" are technological science, that makes it a subcategory of science, and technology-practice that makes it a subcategory of the productive arts

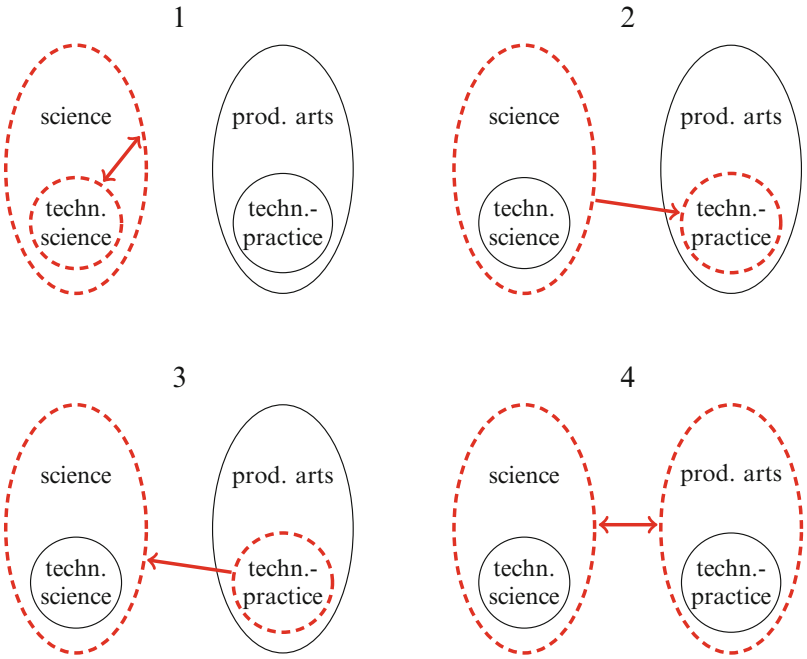

Fig. 2.2 Four philosophically interesting explications of the notion of a science-technology relationship: (1) the relation between science in general and technological science, (2) the role of science in technological practice, (3) the role of technological practice in science, and (4) the relationship between science and the Aristotelian notion of productive arts (that is more general than the notion of technological practice)

First, we have questions about the relationship between science and technology-knowledge, or between science in general and technological science. When discussing this, we can mean by "science in general" either science in the restricted English-language sense that excludes the humanities or in a broader sense that includes them. One important research question is whether the technological sciences differ from other sciences in other respects than their subject matter, for instance whether they have different methodologies or epistemological criteria.[9] Another such question is whether the technological sciences are applied natural sciences, i.e. entirely based on principles referring to objects that are not human-made, or whether additional principles are needed that refer to the human creation of technological artefacts.

Secondly, we have questions about the role of science (in either the conventional or the broad sense) in technology-practice. To what extent is technological practice, such as various forms of engineering, based on scientific knowledge? Today it is commonplace that technology-practice is not just applied science. It also involves other types of knowledge, such as tacit knowledge and (explicit but non-scientific) rules of thumb. What is the nature of such knowledge, and how does it differ from scientific knowledge? (Hansson 2013a; Norström 2011) (This second group of questions should be distinguished from the first group that refers to the relationship between science in general and technological science.)

Thirdly, there are interesting questions about the reverse relationship, namely the role of technology-practice in science (in either the conventional or the broad sense). The Austrian historian and philosopher Edgar Zilsel (1891–1944) showed that Galileo Galilei (1564–1642) and other scientific pioneers depended on the help of skilled workers in order to succeed in extracting information from nature by manipulating it, i.e. making experiments (Drake 1978; Zilsel 1942, 2000). In more recent years, several authors have claimed that it is more accurate to describe

[9]The following six differences between technological and natural science were proposed in (Hansson 2007a).

1. Their primary study objects have been constructed by humans, rather than being objects from nature.
2. Design is an important part of technological science. Technological scientists do not only study human-made objects, they also construct them.
3. The study objects are largely defined in functional, rather than physical, terms.
4. The conceptual apparatus of the technological sciences contains a large number of value-laden notions. (Examples are 'user friendly', 'environmentally friendly', and 'risk'.)
5. There is less room than in the natural sciences for idealizations. For instance, physical experiments are often performed in vacuum in order to correspond to theoretical models in which the impact of atmospheric pressure has been excluded, and for similar reasons chemical experiments are often performed in gas phase. In the technological sciences, such idealizations cannot be used.
6. In mathematical work, technological scientists are satisfied by sufficiently good approximations. In the natural sciences, an analytical solution is always preferred if at all obtainable.

science as applied technology than the other way around (Lelas 1993). The use of technology in science is at focus in most of the chapters that follow.

Fourthly, we can generalize these deliberations to an arguably more philosophically fundamental level, namely the relationship between on the one hand science in the broad sense and on the other hand the productive arts, or goal-directed practical activities, in general.[10] This will in fact be a resumption of the way in which the relationship between science and the arts was studied long before the modern humanities-excluding notion of science, and long before the modern notion of technology that only includes a fraction of the practical arts. The English philosopher Robert Kilwardby (1215–1279) discussed this relationship in a remarkably sophisticated way. He emphasized that a distinction must be made between science in a broad sense (called "speculative philosophy") and the practical skills, but he also pointed out that they are dependent on each other in a fundamental way:

> In as much as we have said something separately concerning the speculative part of philosophy and something about the practical part, now it is important to say something about them in comparison with each other. I ask therefore in what way they are distinguished according to their degree of speculative philosophy and praxis, since those which are practical are, indeed, speculative – it is important certainly that one consider first by speculative virtue what one ought to perform in practical virtue – and, conversely, the speculative sciences are not without praxis. Does not, in fact, arithmetic teach how to add numbers to each other and to subtract them from each other, to multiply and divide and draw out their square roots, all of which things are operations? Again does not music teach to play the lute and flute and things of this sort? Again does not geometry teach how to measure every dimension, through which both carpenters and stoneworkers work? Again, does not one know the time for navigation and planting and things of this sort through astronomy? It seems therefore that every single science said to be speculative is also practical. It seems, therefore, that the speculative sciences are practical and the practical speculative. (Quoted from Whitney 1990, 120)[11]

Seen in this wider perspective, elucidation of the science-technology relationships is important not only for the philosophy of science and the philosophy of technology, but also more broadly for our philosophical understanding of the relationships between human knowledge and human activity, and between theoretical and practical rationality.

[10] In a similar vein, the German historian of technology Otto Mayr has proposed a research focus on "historical interactions and interchanges between what can roughly be labeled 'theoretical' and 'practical' activities, that is, between man's investigations of the laws of nature and his actions and constructions aimed at solving life's material problems." (Mayr 1976, 669).

[11] In his *Opera Logica* (1578) the Italian philosopher Jacopo Zabarella (1533–1589) discussed the same issue, but reached a different conclusion. In his view, the productive arts can learn from science but not the other way around (Mikkeli 1997, 222).

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