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Clocks, Automata and the Mechanization of Nature (1300–1600)

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Abstract: This paper aims at tracking down, by looking at late medieval and early modern discussions over the ontological status of artifacts, the main steps of the process through which nature became theorized on a mechanistic model in the early 17th century. The adopted methodology consists in examining how inventions such as mechanical clocks and automata forced philosophers to modify traditional criteria based on an intrinsic principle of motion and rest for defining natural beings. The paper studies different strategies designed in the transitional period 1300–1600 for making these inventions compatible with classical definitions of nature and artifacts. In the first part of the paper, it is shown that, even if virtually all medieval philosophers acknowledged an ontological distinction between artifacts and natural beings, these different strategies demonstrate a growing concern about the consistency of the art/nature distinction. The next part of the paper studies how mechanical clocks, even before the Scientific Revolution, served as theoretical models for applying mechanistic views to different objects (be they cosmological, physical or biological). The epistemological function of clocks appears to stem from different factors (like the specific manufacturing of late medieval clocks as well as the evolution of 16th-century mechanics) that are listed in this second part of the paper. These factors, combined with the definitional issues raised by automata, explain that clocks became the symbol of a new approach to natural philosophy, characterized by the collapse of the art/nature distinction and the "mechanization of nature".

Keywords: artifacts; nature; mechanism; machines; clocks; automata; motion

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1. Introduction

In *The Advancement of Learning* (1605), Francis Bacon writes [1] (p. 294):

> [. . .] An opinion has long been prevalent, that art is something different from nature, and things artificial different from things natural [. . .] whereas men ought on the contrary to be surely persuaded of this, that the artificial does not differ from the natural in form or essence.

It is hard to deny Bacon's main observation as to the art/nature distinction in the pre-modern period. Aristotle's real position regarding the ontological status of artifacts is a matter of dispute, as it is far from clear that he meant to grant them a substantial or accidental status [2,3] pp. (161–165); [4] (pp. 571–572); [5] (p. 13). Nonetheless, a general agreement among medievals was that artifacts are accidental wholes and an even more universal consensus was that artificial beings are ontologically different from natural ones. By contrast, one of the most salient features of early modern philosophy is the use of machines as theoretical models for understanding nature while denying any essential difference between natural and artificial things. Important studies have already shown how the foundations of modern philosophy lie on a mechanistic worldview encompassing not only the physics of inanimate bodies but also organisms and psychological processes (for recent studies, see [6–11]). But the transitional period starting from the early 14th century, when philosophical discussions over the metaphysical status of artifacts became more and more common, to the early 16th century, remains unknown to a large extent when it comes to the reflections having led to the mechanistic turn of modern philosophy.

This study examines one important factor involved in this change of paradigm that happened between the late Middle Ages and the early modern period (between ca. 1300 and 1600), namely the development of mechanical devices capable of automatic motions such as clocks. It will not be claimed here that this factor was the only one responsible for the collapse of the distinction between *artificialia* and *naturalia* in the early modern period, not even that it was a necessary or sufficient condition in bringing about this theoretical change. Undeniably, other factors were equally important in this process, among which the evolution of the status and definition of mechanics in the 16th century must be cited [7,12] (pp. 93–119) along with changes in the understanding of causation and the general rejection of final causes in scientific explanations [13–15] (pp. 168–211); [16] (pp. 90–115, 150–179) or the use of technological devices as theoretical models in medicine and life sciences in general [17–19]. Still, it will be argued that the problems arising from the development of automatic devices such as mechanical clocks, being independent from those other factors to some extent, was one important partial cause of the collapse of the art/nature distinction. Admittedly, the idea that clocks served as an important example in the change of paradigm regarding natural and artificial things is not new. Important studies have also shed light on the complex story and the various philosophical uses of clocks in modern philosophy. In particular, P.-H. Newmann has underlined the evolution of philosophical interpretations of clocks in early modern philosophy, demonstrating brilliantly that clocks, paradoxically, were first employed to illustrate the animating soul present in living beings before becoming a symbol for mechanistic philosophical doctrines [20].

The ambition of this paper, then, is not to prove the well-known symbolic importance of clocks for illustrating philosophical intuitions in the early modern period. It is rather to provide textual evidences that the concrete invention of mechanical clocks stimulated new positions regarding the distinction between art and nature as early as the 14th century, hastening long before the Scientific Revolution the 'mechanization of the world picture', to use Dijksterhuis' expression [21]. In this study, philosophical 'mechanism' will therefore be taken to mean the doctrine according to which the universe and all it contains can be reduced to mechanical principles, i.e., to the motion and interaction of parts of matter, and lack any essential difference with a complex machine[1]. By highlighting the importance of automata in late medieval discussions that have not been studied so far, including in lesser-known authors, the paper also aims at bringing support to the claim made by Newmann that the philosophical history of clocks, far from being uniform and linear, went through distinct stages, of which the illustrative role of clocks as symbols for mechanical philosophy is only the final phase.

This study is divided into two main parts. The next part of the paper explains the need to reframe the art/nature distinction in light of technological inventions such as mechanical clocks and, more generally, machines capable of automatic motion (Section 2). Then, the different attitudes adopted by medieval and early modern thinkers to tackle this definitional challenge will be presented. Whereas the strategy of different philosophers was to stick to the traditional account of nature by denying to clocks the capacity for self-motion, others acknowledged that the special types of motions produced by artifacts had to be taken into account within a more comprehensive typology of motion, while still others chose to abandon the traditional criteria for differentiating art and nature. From this perspective, the last part of this study underlines the importance of clocks as theoretical models in the late medieval and early modern period in the conceptual elaboration of the 'mechanization' of nature (Section 3). The epistemological function of clocks as theoretical models (ranging from an allegorical role to tighter functional analogies) for the mechanistic program of early modern natural philosophers appears to stem from different factors (like the specific manufacturing of late medieval clocks as well as the evolution of 16th-century mechanics) that are listed in this section. These factors, combined with the definitional issues raised by automata, explain that clocks, more than any other automata, became the symbol of a new approach to natural philosophy, characterized by the collapse of the art/nature distinction and the mechanization of nature (Section 4).

2. Clocks and Automata: The Impact of Technology on Discussions over the Ontological Status of Artifacts

Whereas medieval thinkers generally agreed on the ontological status of artifacts, which they refused to characterize as substances, the issue raised by the type of motion related to artificial forms was a much more debated one. Scholar discussions held at the universities over the status of artifacts and their relation to the notion of nature cannot be detached from the rise and development of technological inventions of that time. The arguments concerning the distinction between natural and artificial things demonstrate that at least some technological inventions played a decisive role in these debates and contributed to reshaping the way philosophers conceptualized natural beings. The case is particularly patent with mechanical clocks, which were first designed—some doubts remaining as to the exact date of their invention—at the end of the 13th century.

While the notion of *automata* was already employed by Aristotle among other ancient philosophers, automata received little attention in ancient discussions over the definition of nature [23,24], which was treated in the Aristotelian tradition in connection with the analysis of motion. Mechanical clocks posed a new problem for framing the distinction usually drawn between artificial and natural beings. According to two much passages of Aristotle's *Physics* much commented in the Middle Ages (*Physics* II 1, 192b13-15 and 192b21-23), the difference between nature and art depends on the presence (in the case of a natural being, be it animate or not) or absence (in the case of an artifact) of an internal principle of motion and rest[2]. Unlike water clocks or other ancient devices that only move in virtue of some agent or external force presently applied to them, mechanical clocks are objects that seem to move by themselves—owing to their internal constitution—and that, once set in motion, do not require anything external to move. The philosophers' interest for automatic devices certainly did not start with the invention of mechanical clocks but was nonetheless intimately connected with it. In the 13th century, Peter Peregrinus and his attempt at making a wheel of perpetual motion are mentioned by Roger Bacon in his *De secretis*. As suggested by recent studies [26,27], a new interest emerged in the first half of the 14th century for the ontology of artifacts, and it is no surprise to see mechanical clocks appear in the arguments listed by one of the most influential thinkers on the topic, namely John Buridan, who makes the following remark[3].

> The clock has in itself the principle of its local motion and the candle similarly has the principle of its burning the wick.

The comparison between the clock and the candle shows that Buridan does not consider the clock as a unique case deserving special consideration. But the presence of clocks in other texts of the same period indicates a real interest for artifacts involving automatic mechanisms and the theoretical issues they involve. Walter Burley (ca. 1275–1344), for instance, takes the example of clocks when discussing the intrinsic (*per se*) character of natural motions([29] (VII, f. 203va). In the same context of scholastic writings, similar uses of clocks can be found in various philosophical writings of the 15th and 16th centuries (see for instance [30] (f. 70ab) and [31] (II, f. 18va)).

These discussions about clocks in contexts involving the definition of nature show that such artifacts raised a new problem considered by many as very serious. The seemingly spontaneous and automatic character of motion in clocks appeared to challenge the criterion of an internal principle of motion and rest as a relevant distinguishing mark between art and nature. In face of this definitional problem, at least three main types of solutions were designed by philosophers from the late Middle Ages to the early modern period. It is already worth noting that these solutions were first stimulated by a will to maintain the distinction between *artificialia* and *naturalia* and by the conviction that this definitional challenge could be overcome. The differences between the solutions offered, however, had important metaphysical consequences for the art/nature distinction. For the sake of clarity, it will be more convenient to present these strategies separately but it must be emphasized that they should not be viewed as chronologically ordered stages, being more coexisting strategies proposed by various thinkers in the selected period, nor as totally distinct lines of argumentation insofar as they sometimes overlap in the texts discussed below. A detailed presentation of these solutions—from the more to the less 'conservative' regarding the traditional art/nature distinction—is in order.

2.1. Denying That Artifacts Have an Internal Principle of Motion

The first main strategy against the problems posed by artifacts regarding the definition of nature consists in plainly refusing that artifacts possess some internal principle of motion due to non-natural properties. In short, although artifacts like clocks seem to move by themselves, their motion is in fact caused by the natural tendency of their constituents and is, thus, natural.

This argumentative strategy was indeed available to those who rightly pointed out that clocks are ultimately moved by the natural tendency of the weights that are parts of their mechanisms. Alessandro Piccolomini (1508–1579), a representative of this move, writes[4]:

> [. . .] that the force moving against nature, like in a clock for instance, the weight or another similar force that moves the main wheel, comes from its heaviness, like from its nature [. . .].

To appreciate the relevance of this argument, it must be recalled that the first models of mechanical clocks were based on an escapement mechanism in which a suspended weight was responsible for the cyclic movement of the main wheel, causing also the upward motion of the hand of a clock, despite its being a heavy body (see Figure 1). This model is what Alessandro Piccolomini has in mind when he describes the real cause of the seemingly non-natural motion of clocks. The argumentative strategy, from this point of view, remains valid even for later improvements like the pendulum clock invented by Christiaan Huygens in the mid-17th century, whose main motion is also primarily due to the weight of its central component.

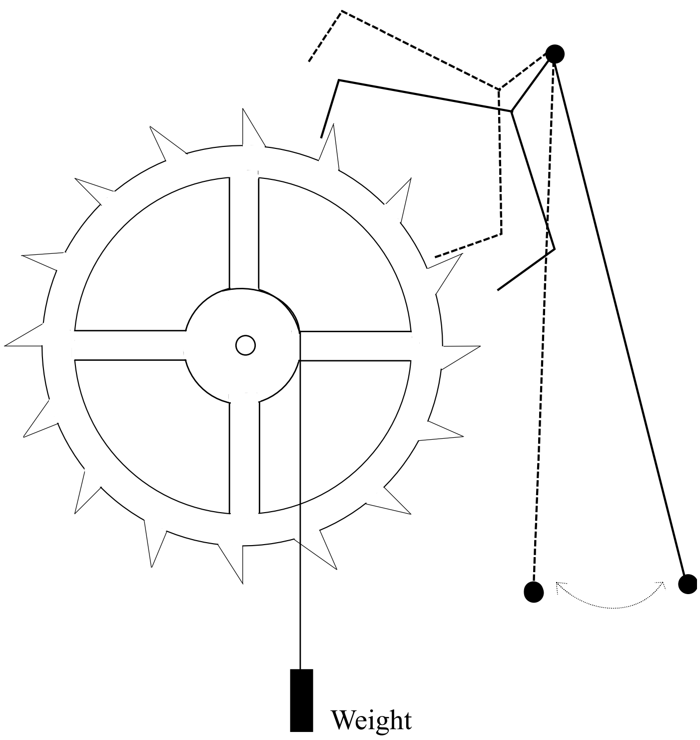

Figure 1. Simplified diagram of an escapement mechanism.

Piccolomini is not an isolated case and his opinion is shared by several 16th-century thinkers. The comparison of the different formulations of the same general answer show, however, interesting variations. While someone like Francisco Valles (1524–1592) wholly accepts this solution and refuses to concede that the internal motion of clocks is artificial [33]

(f. 22vb), others like Benito Pereira (1535–1610) offer a more nuanced description of the functioning of clocks, claiming that some motions of mechanical clocks are natural whereas others are artificial, even if their ultimate cause (the weights at the core of such devices) is natural [34] (VII, c. III, f. 246BC).

A related strategy drew on the distinction of types of principles and, more precisely, in acknowledging that natural beings possess an internal principle of motion only in a certain sense. This move constitutes the main argument of Peter Tartaret (ca. 1460–1522) against the view that many natural beings have no more internal principle of motion than clocks; see [31] (II, f. 18va). Just like an artifact may be in a state of motion once moved by an extrinsic cause and, yet, be entirely dependent on this cause as to its motion, many natural beings like inanimate bodies do not seem to be the active cause of their own motion. Trying to clarify the true meaning of Aristotle's criterion of an internal principle of motion, Tartaret recalls that some authors like Avicenna had interpreted this expression as referring to an *active* principle of motion ([35] (I, c. 5, ff. 16va–17ra); on Avicenna's position, see [36] (pp. 213–306); on the problem of interpreting the 'principles' involved in Aristotle's definition(s) of nature, see [25]). But Tartaret underlines that what truly differentiates a natural being from an artificial one is not an active principle of motion but rather a *passive* one. Indeed, possessing a passive principle of motion represents the universal characteristic that every natural being has internally. Being able to be moved in a specific way is what is truly essential to all natural things. According to Tartaret, matter, as opposed to form, constitutes the metaphysical principle accounting for this passive potency. By contrast, an artifact may well contribute to the motion of an object because of its figure, but an artifact *qua* artifact is devoid of any passive potency that would incline it toward a certain shape, configuration or motion[5]. The case of clocks, therefore, falls into the same category as other artifacts and does not seriously threaten the well-foundedness of the art/nature distinction (see [31] (II, ff. 20ra-rb)).

Agostino Nifo (1473–1545) also mentions clocks when commenting on Aristotle's opinion about artifacts. In the context of discussing motion without contact (when there seems to be no contact between the moving cause and something moved), he notes that the problem of the real cause of such motions is salient in the case of what the Greeks called "*automata*." As for clocks, Nifo seems to acknowledge that the ultimate cause of all their motions is the weight playing the role of the first cause in the chain of causes composing such devices [30] (f. 70ab). In his *Exposition on Aristotle's Physics*, he relies on Simplicius' position on the problem to claim that artifacts have an internal principle of motion and rest *but not as artifact*. The problem of determining whether artifacts have an intrinsic principle of motion is thus solved owing to the possibility of considering a thing *qua* a certain kind of object or under a certain mode, so to speak. A thing may be said to have an internal principle of motion when it is considered in a certain way, whereas this point may be denied when it is taken from another point of view. *Qua* artifacts, objects such as clocks do not have any internal principle of motion although considered as natural objects, they do[6]. Evaluating the consistency of this theoretical strategy exceeds the scope of this paper. Let us only note that this twofold description of objects allows Nifo to save the appearances, i.e., to admit that things similar to automata move by themselves in a certain sense while holding to the definitional principle according to which, strictly speaking, only natural beings have an intrinsic principle of motion.

The answers provided by Alessandro Piccolomini, Francisco Valles, Benito Pereira and Agostino Nifo to the problem raised by artifacts like clocks and automata are formulated in different ways but are nonetheless convergent. They aim at establishing that these objects do not have internal principles of motions and that the core distinction between art and nature, inherited from Aristotle, is safe. The evolution of clocks in the 15th century, however, went against the main point of this solution. Indeed, the invention of *coiled springs* in the 15th century and their use in many technological devices including clocks led engineers to gradually abandon the escapement mechanisms using natural gravity that were used in the first mechanical clocks and on which the most powerful philosophical arguments for the natural character of their motions were based. But it is also because this type of answer probably requires to concede at least some type of distinction to fully make sense (between two types of motions in the case of Benito Pereira, for instance, or between two ways of considering the same object according to Nifo) that other thinkers felt the need to offer other solutions to the problem.

2.2. Granting a Special Status to Artificial Motions

A second strategy, explored by several thinkers of the same period, consisted in attributing a special status to the particular types of motions caused by artifacts. This second strategy was not incompatible with the previous one but its core point amounts to something different and, thus, can be analyzed in its own right as a special solution to the problem. Granting a special status to the types of motions caused by artifacts meant, in particular, to show that such motions are not proper motions but modes of motions. In other words, the strategy amounts to saying that artifacts do not really have any internal principle of motion but are responsible for a certain modification of the natural motion of bodies, where "modification" should be understood as acknowledging that artifacts add a mode to the natural tendency of bodies.

In the late Middle Ages, defining speed or related properties like acceleration and deceleration as *modes of motion* and motion itself as a *mode of bodies* was not uncommon at all. This definition allowed natural philosophers to avoid the concept of 'accident' to characterize the ontological status of motion, which was usually regarded as a problematic way to define it due to the real distinction between a substance and its accidents most philosophers were inclined to posit. Besides, although the term (*terminus*) of motion is an accident, since what is acquired through motion is a new quality, a new place or a new quantity, there were good reasons to think that motion as such was not a category and, hence, deserved a special ontological status (on this problem see the classical study of [38] (pp. 9–25); [39] (pp. 61–143)). In the case of variations of speed, for instance, defining acceleration and deceleration as modes would allow one to avoid the undesirable consequence that such properties are accidents of accidents, if one were to concede that motion is already an accident of some body. In the special case of artifacts, modes could be used as conceptual devices ready to explain those motions precisely caused by artifactual forms. This made possible to claim that, in artificial bodies, motion as such is intrinsically natural although artifacts *modify* some of its properties.

Crisostomo Javelli (ca. 1470–ca. 1538) is a proponent of this solution. Javelli notes that the shape of an object modifies the properties of an object's motion[7]:

> Indeed, if a plane figure is made, it will cause in the artificial thing a straight motion, and a circular motion only with difficulty. If, however, a pyramidal or spherical figure is made, the thing will be inclined by this figure to a spherical motion, therefore etc. [. . .] Therefore you would dissolve the two objections, turning to the first part, noting that it is different to have in itself a principle of motion and to have in itself a principle of quality or mode of motion. Now the first is proper only to a natural form, like it is proper to earth or to a stone to move downward, because they have heaviness, which is a natural quality. Thus, no figure impressed or earth or a stone, unless with heaviness, will ever move downward naturally.

The argument presented here relies on the concept of figure, which clearly affects the motion of a body without being entirely reducible to matter or quantity of matter, so as to point out the causal efficacy of artifacts as figures introduced into matter through art (see for instance [31] (f. 18va) for another neat presentation of the argument). A body is more inclined to rectilinear motion when it is flat, whereas it is more inclined to circular motion once shaped as a pyramid or a sphere. Insofar as shapes can be introduced through art, it must be admitted that artifacts add a mode to the motion of natural bodies. The point here is not primarily an argument in favor of the reality of artifacts, nor in favor of some special property brought about by artifacts in general. It is, rather, an argument drawn from a common observation about the influence of shapes—be they natural or artificial—on motions. But it is clear from the text quoted above that Javelli attempts to explain the ontological status of motions generated through artificial shapes while maintaining that, strictly speaking, artifacts do not have any internal principle of motion.

Aiming to clarify the distinction between a natural form and an artificial one, Javelli specifies three conditions for the form received in a subject to be natural [40] (II, q. 2, f. 89):

a. to be received through active and passive qualities introduced by a natural agent

b. to be received in matter immediately, because the subject of a substantial form is a being in pure potency

c. to be received by the whole subject (not just the surface)

By contrast, artifacts are generated essentially through local motion and are impressed on some matter already informed by a substantial form. But, most importantly, artificial forms mainly consist in the modification of the surface of the object, whereas natural ones determine the whole subject, as stated by condition (c). Javelli lists the different types of modifications involved in the production of artifacts: cutting (*incisio*), union (*compaginatio*), hammering (*malleatio*), melting (*liquatio*), hardening (*induratio*). That these changes only modify indeed the surface of objects is far from clear (even more so provided the ontology of qualities proper to the Aristotelian background of the time). What is beyond doubt, however, is Javelli's will to maintain the distinction between *artificialia* and *naturalia* together with the traditional criterion of the intrinsicality of the principle of motion in natural bodies by appealing to the concept of mode of motion.

Similar strategies can be detected in the 16th century. Toletus makes the very same distinction—referring to the *Averroes latinus*—between motion and the quality or mode of motion to explain what type of action is brought about by art [41] (f. 46vb). The Coimbran commentators, just like Francisco Suárez, equally attribute to artifacts the property of modifying the motion of natural bodies, while they also ground the classical distinction between artificial and natural beings on the Aristotelian criterion of an internal principle of motion[8]. Francisco Suárez, for instance, makes the same observation as to the causal role of figures and shapes in the motion of natural bodies. Being dispositions of quantitative parts, figures are modes of quantity. Insofar as quantity is not an active principle of change, figures cannot be active principles of change either. The causal role of a substance's figure, therefore, can only be to modify more or less its resistance against the action of other bodies upon it. The shape of an instrument such as a knife allows it to offer less resistance against another body, making possible to cut this body more easily. More generally, figures—be they the result of a natural state or of a craftsman's activity—can modify the motion of a natural body but they cannot be said to bear any causal role as internal principles of motion[9].

The fact that artifacts modify at least in a certain sense the motion of natural bodies was hard to deny. The whole point of the discussion over clocks and automata was to avoid saying that they do so in providing something intrinsic to explain their motions. That this modification was due to a mode was one possible way to go. But the problematic ontological status of modes as well as doubts regarding their ability to ensure this theoretical function explain that in the eyes of many this solution was insufficient.

2.3. Redefining the Art/Nature Distinction

A third strategy—the most radical with respect to the traditional art/nature distinction—was to modify the definitional criteria used to characterize artifacts. The discussion of artifacts by Giacomo Zabarella (1533–1589) is a perfect example of this attitude (on Zabarella's definition of art, see [44] (esp. pp. 107–130); see also [45]). Zabarella's position is interesting to mention here for two main reasons. First, because he is rightly considered as one of the most important masters active in Padua in the 16th century. Given the importance of the Paduan school for the gradual deconstruction of Aristotelianism in the early modern period, Zabarella's position represents an important step in a new way of framing the concept of nature. Second, his position demonstrates the importance of newly available texts from Ancient philosophy in the context of lively discussions led in the Paduan milieu for finding new definitional criteria regarding artifacts.

Zabarella admits that the sole criterion of an internal principle of motion is not good enough to differentiate art from nature since, according to him, it is not consistent to deny that some artifacts have such a principle. Looking for a better way to distinguish artifacts from natural beings, Zabarella discusses the opinion of his colleague in Padua Federico Pendasio (ca. 1525–1603). Pendasio relied on the types of parts proper to artifacts and natural beings to show that the true criterion of distinction between them must be found in the structure of their internal composition: Whereas artifacts may have artificial *or* natural *integral* parts, it is not possible for natural beings to have artificial parts. The distinction of artificial and natural beings lies, in other words, in the *possibility* proper to artifacts to have parts of both types. This position is presented as an improvement of Alexander of Aphrodisias' definition of artifacts, which was later defended by Simplicius, according to which whereas natural things have natural things as *essential* parts (i.e., parts making up a thing's essence), no artifacts have artificial things as essential parts. Pendasio modified this distinction by replacing the notion of essential part by that of integral part (i.e., a part that can be separated from its whole through division): An artifact has natural things as parts and does not necessarily have artificial things as parts, whereas a natural being necessarily has natural things as parts [46] (f. 320a).

It may be suspected that a solution like Pendasio's begs the question or, more precisely, fails to provide an impredicative definitional criterion, since the term 'artificial' appears in its own definition. Be that as it may, Zabarella's main objection to this approach is that such characterization of artifacts is not powerful enough to capture their essence since an adequate definition of artifacts must pin down the type of *principles* that characterize their mode of being[10]. Therefore, if the notion of principle must be included in the distinction between artifacts and nature, the traditional definitional criterion must be reshaped. Evaluating the positions of Avicenna (according to whom nature is an active principle of motion and rest) and Simplicius (for whom nature must be defined as a merely passive principle), Zabarella is well aware of the difficulty of determining whether this principle of motion must be understood as an active or a passive one [48] (IV, c. 2–5, pp. 316–324) and eventually chooses to define nature as an active *and* passive principle of motion [48] (IV, c. 6, p. 324, ll. 17–20). The type of solution favored by Simplicius or Tartaret, i.e., restricting to a passive principle the definitional criterion of nature, is rejected as it entails that all motions involving artifacts, like that of a boat moving on water, would be natural [48] (IV, c. 6, p. 325, ll. 13–26; see Figure 2).

	Avicenna	**Simplicius or Tartaret**	**Zabarella**
Type of principle meant in the definition of nature	Active principle only	Passive principle only	Both active and passive principle

Figure 2. Comparison between competing definitions of nature.

Incidentally, Zabarella points out in his *De rebus naturalibus* the different formulations one finds in the Aristotelian tradition concerning nature, which is alternatively presented as a principle of motion (*principium motus*) or as a principle of making (*principium factionis*). However, even if Zabarella denies artifacts an internal principle of making, he does not draw on this conceptual variation for differentiating art and nature [48] (IV, c. 2, p. 316, ll. 25–27; IV, c. 5, p. 323, l. 15; VIII, c. 4, p. 408, l. 6). But in his commentary on the *Physics*, Zabarella does take into account the causal efficacy of artificial and natural forms. There, he points out that one characteristic of a natural form is that it can bring about another form of the same species, whereas an artificial form alone, without the help of a craftsman, can never do so. This is why, according to Zabarella, a natural form can be called "nature" whereas an artificial form cannot be called "art" (for related analyses led at the same period by Toletus, see [41] (II, c. 2, q. 6, f. 54vb)). According to Zabarella, by simply characterizing nature as an internal principle of motion and rest in the second book of the *Physics*, Aristotle in fact aimed at differentiating natural and artificial *forms*, and not art and nature as such (on this point, see [44] (pp. 114–115)).

The fact that artifacts have an internal principle of motion leads Zabarella to explain that it is the *way* of possessing this internal principle of motion that differentiates art from nature. Whereas natural beings possess their internal principle of motion by themselves (*per se*), artifacts have their internal principle of motion by accident[11]:

> [. . .] Therefore it must be noted that the difference between natural and artificial things does not lie in the fact that natural things have a principle of motion in themselves, while non-natural things do not. On the contrary, since all these are bodies, it is necessary that, having a principle of motion in themselves, the difference is this, that natural things have by themselves a principle of motion in themselves, that is, insofar as they are such, while non-natural things have a certain principle of motion in themselves, not by themselves however, but by accident, because [they have it] not insofar as they are such, that is, artifacts [. . .].

The internal principle of motion proper to clocks and automata is generated by the craftsman arranging the materials composing the object in a precise way. Once set in motion, such objects do move by themselves but the origin and modality of this principle of motion is different and account for the distinction between art and nature.

Zabarella refuses to attribute to artifacts the same categorial features as natural beings. Some authors, like the physician Pietro Torrigiano de' Torrigiani († ca. 1320), had expressed the view that artificial forms could be considered in a certain way as substantial forms insofar as they play with respect to artifacts a role similar to substantial forms with respect to natural beings [49] (III, com. 58, f. 148vG). Zabarella mentions arguments in the same vein put forward by Simplicius but he strictly refuses that an artificial form may be called a substantial form[12].

In the course of explaining the relation between accidents and their causes, Zabarella provides further criteria for distinguishing an artifact from a natural being, which also enables him to clarify what differentiates an artificial form from other accidental forms. He relies for doing so on the scholastic distinction between the process of coming into being (*esse in fieri*) and the fact of being fully actualized (*esse in facto*). Zabarella underlines that whereas operations of the soul such as walking, talking, feeling and the like cannot exist without the presence of their cause, artifacts can because their being does not only consist in *esse in fieri*. However, artifacts are not the only types of accidents whose being consists in *esse in facto*. Other accidents having *esse in facto* like smells and tastes, unlike artifacts, cannot remain without their causes, but some non-artificial accidents also possess this property [48] (XI, c. 10, p. 528); see Figure 3).

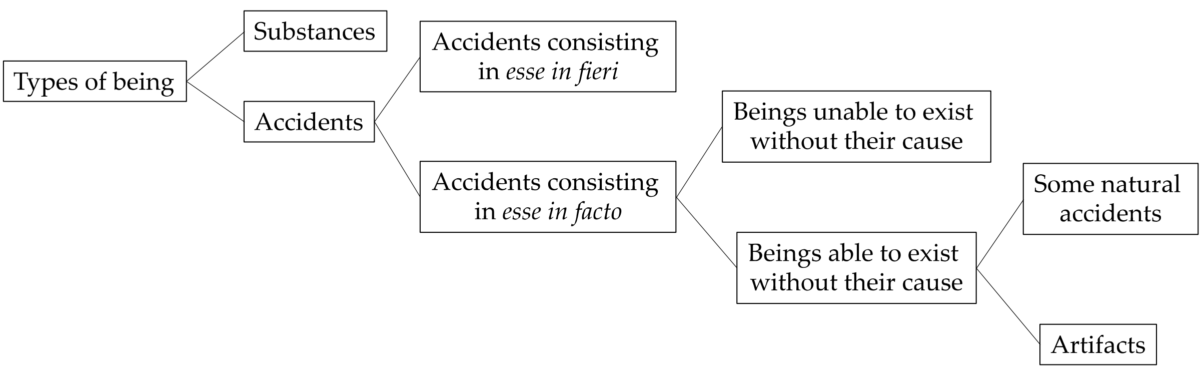

Figure 3. Types of beings and classification of artifacts according to Zabarella.

To summarize, Zabarella's discussion of artifacts offers a good example of someone willing to maintain a core distinction between artifacts and nature but who drops the traditional criteria used to define them. The attitude of Zabarella in light of the problem posed by automata exemplifies a third strategy different from the two previous ones, which undertakes to redefine the art/nature distinction by replacing the traditional criterion that he considers as insufficient (see Figure 4).

	First strategy *E.g. Alessandro Piccolomini, Francisco Valles, Benito Pereira Agostino Nifo*	**Second strategy** *E.g. Crisostomo Javelli, Toletus, Francisco Suárez, Coimbrans*	**Third strategy** *E.g. Giacomo Zabarella*
Acceptance of the traditional criterion	Yes	Yes or only partially	No
Alternative solution	Ø	Artifacts add a *mode* to the intrinsic tendency of natural motion	Distinction between having an internal principle of motion *by itself* or *by accident*

Figure 4. Comparison of the three strategies.

3. Clocks and the Conceptual Modelling of the Mechanization of Nature

The attempts described above to deal with the case of clocks and automata in an 'Aristotelian' framework acknowledging the distinction between natural and artificial things demonstrate the difficulties faced at the dawn of the modern period by the scholastic conceptuality with respect to technological inventions.

The invention of mechanical clocks and the growing importance of automatic devices from the 16th century onward constitutes one of the many factors that took part in the gradual collapse of the art/nature distinction typical of early modern philosophical systems. The recurrence of clocks in philosophical discussions indicates the symbolic and theoretical importance attributed by philosophers to these objects for the rise of mechanistic trends in this period. Far from being obvious, the reason of this interest deserves some explanations and comments, which will constitute the second part of this paper.

3.1. The Clock Analogy in Natural Philosophy

As Paolo Rossi rightly pointed out in an important study on the relation between philosophy and technology in this period [50], the profound changes that transformed the core concepts of philosophical thinking between 1400 and 1700 were partly caused by factors happening outside of the academic and, more generally, intellectual world. The role played by engineers and inventors in the development of practical mechanics can by no means be detached from the evolution of theoretical mechanics and its use for conceptualizing new explanatory models for natural processes. But why did clocks in particular enjoy such popularity in philosophical discussions? Why did clocks, more than other automata, become a symbol for the mechanistic philosophies of the Modern era?

First, because clocks provided simple examples of automata useful for modelling motions observable in nature, not only for those of planets and stars but also for livings and animate beings. It has now been established that Descartes' project of reducing biological phenomena to purely mechanical processes was anticipated to a large extent in the 16th century. Philosophers and physicians did not always understand the term 'mechanical' in the sense of 'agreeing with the laws of mechanics' but often more generally as meaning 'being like a machine' (see [51] (pp. 13–14); see also [17]). This broader use of the term 'mechanical' contributed to preparing the mechanistic turn of philosophy independently of the advancement of theoretical physics. Even before Bernardino Baldi's translation of Hero of Alexandria's *Automata* in 1589, drawing on mechanical devices for explaining biological functions had become commonplace, and an important part of Descartes' forerunners were physicians or came from a medical background. It is in 1554 that Gómez Pereira, in his *Antoniana Margarita* [52], denies consciousness to animals and defends the view that animal bodies can be explained as mechanical devices. To what extent Descartes was inspired by Pereira's model is a matter of dispute, but it is worth noting that Pereira, coming from a medical background, drew on the knowledge and advances of the medical sciences of his time for building his theories. The Belgian anatomist Andreas Vesalius (1514–1564), active in Padua, describes the making of the human body as a "*fabrica*" on the model of manufactories [53]; on the scope and historical importance of this work, see [18] (pp. 38–45)). Vesalius compares the articulations of the bones with mechanical joints employed for doors and similar devices.

The fact that this use of mechanistic models was relatively independent from anti-Aristotelian theories of motion and nature explains that even philosophers trained and working within the scholastic traditions were inclined to use automata and clocks as analogical models for the motion of animate bodies. Ludovico Boccadiferro (1482–1545), active in Bologna in the first half of the 16th century, compares in this way the motion of the human body with the motion of machines, taking the clock as an example of mechanical devices capable of spontaneous motions[13]:

> Aristotle [. . .], because this is a difficult thing, resorts to an example, and he says that the motion of animals is similar to the local motion of many machines when they are moved; one part moves another, like those spontaneous machines are made that are moved by themselves in the motion of a clock. [. . .] Secondly, just as in their motion one part moves another like in a clock, the greater wheels in the motion of a chariot are moved, while the smaller are at rest, or if they are not, they seem however to be so because they do not move with such speed as in animal motion, because one part prevents another, because hotness moves the nerves, the nerves [move] the muscles and thus one part is at rest during the motion of another, because one part moves another one, like [when] we walk moving the right foot we lean upon the left foot. There is another similitude, because iron is in the chariot, and the machines and the ropes are just like the bones and nerves in an animal. Thus, there is a similitude in the motion of the machines, the chariot and the animal [. . .].

The example of clock, in this passage, illustrates the alternance of motions and rests typical of natural beings. Due to the similarity between the composite character of their motions and the alternating rhythms of animate beings, clocks represent elementary automatic devices providing a well-fitting analogy for mechanism as a general philosophical theory (on automata as epistemological models, see [55,56]. The analogical resources found in clocks explain that philosophers trained in a scholastic or Aristotelian tradition like Giovanni de Guevara in the early 17th century, despite maintaining a distinction between art and nature, could be more easily inclined to describe the cosmological order of the universe as a complex machine, see [57] (ff. 3–4).

The reflections on automata paved the way for the collapse of the distinction between natural and artificial things not because they led to eliminate the traditional concept of nature right away, but because they allowed for an integration of mechanical devices within the sphere of nature. A major theorist of mechanics like Giuseppe Moletti (1531–1588) conceived nature itself as using mechanical devices, blurring consequently the distinction between natural and artificial motions[14]. There exists an "art of mechanics" underlying the operations of nature according to Moletti. Nature, personified as an agent operating by art, represents in this case the ultimate cause whose productions constitute the source of inspiration for human art.

The example of Moletti is here quite telling. Automata could serve as key epistemological devices in the transitional period preceding the Scientific Revolution because, beyond their mechanical behavior, their function-oriented character still allowed for a teleological model which, in line with the scholastic tradition, represented the ultimate explanation of the way things are. In the 16th century, philosophers and scientists could therefore integrate such epistemological models into natural philosophy without fully opposing mechanism and teleology.

3.2. The Clock as an Allegory: A Scheme for Mechanism

The importance of clocks as theoretical models for the rise of mechanism in early modern philosophy lied in their usefulness for major scientific concerns of the time and, in particular, for their ability to model the gradual mechanization of physics and astronomy. But beyond the explicit analogies one could establish between the kinematic properties of clocks and various aspects of nature, the properties of clocks also made it possible to employ them in a broader way as an allegory for mechanism as a general philosophical theory, i.e., as a concrete example for an abstract idea. Let us explicate this point a bit further.

The internal constitution of clocks with their different wheels provided a miniature of the cosmos that is still nowadays part of popular imagery. Prior to the Copernican and Keplerian advances, the complex articulation of wheels proper to clocks served to represent the complicated relations between cycles and epicycles of the celestial bodies' trajectories. The description of cosmological laws by analogies with clocks explains the importance of artifactual models like automata in early modern theories of nature that went along with the broader use of such devices for analyzing concrete bodies and organisms. The image of the clock for describing the universe can already be found in Nicole Oresme in the 14th century [59] (II, c. 2, p. 289):

> When God created the heavens, He put into them motive qualities and powers just as He put weight and resistance against these motive powers in earthly things. These powers and resistances are different in nature and in substance from any sensible thing or quality here below. The powers against the resistances are moderated in such a way, so tempered, and so harmonized that the movements are made without violence; thus, violence excepted, the situation is much like that of a man making a clock and letting it run and continue its own motion by itself. In this manner did God allow the heaven to be moved continually according to the proportions of the motive powers to the resistances and according to the established order [or regularity].

Even well after the progress of early modern astronomy, the image of the clock remained a dominant metaphor for describing the behavior of celestial bodies but also, more generally, mechanical explanations. While the analogical function of clocks had served to legitimize the pioneer mechanistic approaches of nature, the scientific advances of the late 16th and 17th centuries, leading to a gradual dismissal of strict comparisons between clocks and the physical universe, substituted it with a more allegorical use. Thus, clocks became a well-fitting image for the abstract concept of 'mechanism'. As is known, the "machine of the world" (*machina mundi*) was an expression coined by John of Holywood in the first half of the 13th century to designate the universe created by God. The fortune of this expression, quoted by Robert Grosseteste, Pico della Mirandola, Nicholas of Cusa, Clavius and Copernicus, was such that it was still familiar to the 16th-century commentators of the *Mechanical Problems* including Galileo who lectured on this text in Padua (on the meaning of the "machine of the world" for early modern philosophers, see [60].

As such, however, neither the notion of machine nor the idea of mechanism carries any particular picture or scheme. It appears that clocks somehow served as a concrete scheme for the abstract philosophical theory of mechanism or, rather, for the mechanistic theories of the universe. A transition from an explicit analogy to a metaphor paving the way for a more general exploitation of clocks' allegorical power can be seen when the French humanist Peter Ramus (1515–1572) compares the sky with a universal clock [61] f. 119: "*Caelum est horologium universi mundi* [. . .]"). But one of the clearest examples of an allegorical use of clocks for illustrating a mechanical hypothesis is Kepler, who employs the clock as an allegory to eliminate accounts of astronomical motions based on the heavens' souls in favor of a mechanical explanation. The "machine of the world" is explicitly identified with a clock in his *Letter to Herwart von Hohenburg*. Kepler claims that his purpose "is to show that the celestial machine is not a kind of divine being but a kind of clockwork (the one who believes the clock to be animated attributes the glory of the craftsman to his work) because the whole variety of motions depends upon a single, corporeal magnetic force in the same way all motions of a clock depend on a very simple weight. I also show that it is possible to determine this physical cause in a numerical and geometrical way" ([62] (p. 146), trans. J. Mittelstrass in [63], slightly modified). The clock, in this passage, serves to exemplify the general idea that a physical system containing an apparent variety of motions can be reduced to one single principle. The fact that Kepler's peculiar ideas were still very much indebted to Renaissance vitalism should prevent us to see him as a typical representative of mechanical philosophy. But it is all the more significant that, like Kepler, important actors of the Scientific Revolution still reluctant to accept universal mecanism appealed to the symbolic function of clocks to integrate pieces of mechanistic explanations in their worldview. This more allegorical use of clocks explains that in the 17th century, by the time mechanical philosophy had become dominant, the neologism '*horologialiter*' was sometimes employed as a short-cut for 'in a mechanical way'.

3.3. Clocks and the Evolution of 16th-Century Mechanics

This association of clocks with the abstract idea of mechanism may not be only due to the most obvious reasons that come to mind, that is, the above-mentioned similarity between their motions and astronomical ones, to which may be added the analogy between their regularity and that of laws of nature as well as the foundational role of clocks for the new quest of *measuring* natural processes that became central to modern physics. It probably also stems from deeper reasons connected to the methods proper to 16th-century mechanics. A major change in the epistemic status granted to mechanics in the 16th century was the scientific character that philosophers and scientists started to attribute it, as several studies have shown [7,12] (pp. 93–119). A consequence of this evolution that has received little attention from scholars is its impact on the distinction between artifacts and nature. Indeed, the evolution of mechanics toward the status of a theoretical science whose object became increasingly identified with the laws of nature (rather than with the practice of producing goods for human benefits like the "mechanical arts") had important consequences for this redefinition.

From the early 16th century onward, the set of texts and treatises connected with the new interest for mechanics comprised a great deal of problems involving machines and their motions. At that time, the two most important sources for mechanics understood as a theoretical science were the various treatises attributed to Jordanus de Nemore, on the one hand, and the newly recovered *Problemata mechanica* (edited in 1517) attributed to Aristotle, on the other hand. Given the intimate connection between mechanics understood as a theoretical science, the empirical practices of machine construction and the philosophical problems connected to automatic devices, it is no surprise to see Agostino Nifo quoting the newly recovered *Problemata mechanica* when discussing the status of artifacts such as automata [30] (f. 70ab)[15]. But one of the most remarkable aspects of the two above-mentioned sources is that, despite their differences, both based their approach of mechanics on the properties of the balance, which was in turn analyzed through the properties of the circle. In the *Problemata*, core theorems of statics like the law of the lever are demonstrated through the properties of the circular trajectory of beams suspended on the balance, while central notions of the Jordanian theory of weights like the concept of positional weight (*gravitas situalis*) also depend on the displacement of beams along circular paths. The properties of weights, in particular, are studied through the analysis of the circular motions of the beams resulting from the alteration of their weights or similar cases (see Figure 5).

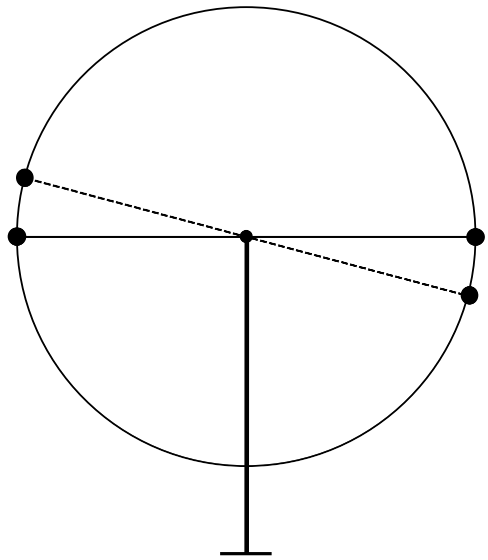

Figure 5. Circular motion of an equal-arm balance.

This approach was explicitly endorsed by central actors of the mechanistic revolution. Galileo, just like Guidobaldo dal Monte, claims that all properties of motion established by mechanics are reducible to a limited list of simple machines comprising for instance the inclined plane, the pulley and the screw (this last device being especially interesting given that screw fasteners had started to be used in the manufacture of clocks in the 15th century), which are themselves reducible to the properties of the lever, in turn itself reducible to the properties of the balance [65] (p. 97). The making of clocks not only involved a direct application of laws of circular motions but also calculations based on the convertibility of rectilinear motions into circular ones through mechanisms similar to the pulley. The importance of circular motion and its properties for understanding the composition of forces, weights and trajectories might partially explain the widespread use of clocks a concrete example illustrating the laws of mechanics and its applications for describing natural processes (for more details on the mechanisms involved in clocks in early modern period, see [66].

At any rate, many theorists of mechanics underlined the connections between the principles of motion demonstrated by clocks and the general laws of mechanics governing the universe. Here again, it is worth quoting Giuseppe Moletti who takes the example of clocks as complex devices lacking any substantial difference with simple machines like the lever, illustrating the applicability of these simple mechanical devices—from the study of which all motions can be understood—to more complex phenomena. The only difference between elementary devices (which are called mere "instruments" because of their simplicity) and more complicated machines like clocks is a matter of degree, not of essence [67] (p. 83):

> PR: What I have said of pulleys I also say of artillery, of mechanical clocks, and of all the things that fall to the mechanic, such as mills of all sorts, machines for drawing water, all instruments to make forces, and so on. [. . .]
>
> Signor AN: I can see that the machine is the subject of mechanics, and I have read in Vitruvius that he defines it thus: 'the machine is a perpetual and continuous construct of material that has the greatest force for the movement of weights.' But I do not understand his distinction between machine and instrument.
>
> PR: The difference is clear because the one is distinguished from the other by workmanship. We would say that the mechanical clock is a machine, but the lever with which we move weights we would call an instrument. In the clock there is much workmanship and many gears; in the lever little workmanship and no gears. But it remains to be seen if there truly is a difference between them,

because more or less workmanship does not make a sensible difference or change the species.

In the *Dedicatory Letter of Filippo Pigafetta* to Guidobaldo dal Monte's *Mechanicorum liber*, all these elements are also present, i.e., the reducibility of mechanical devices to the balance, the identification of practical mechanics with the making of clocks and the ability proper to mechanics to produce miniature of the universe[16]. But one of the clearest instances of this tendency to use clocks for justifying the general applicability of mechanics to the universals laws of motion is Galileo himself. Key to Galileo's philosophical enterprise is the postulate of the intrinsic measurability of natural processes. The measurability of natural motions, based on their regularity, explains Galileo's interest for clocks as a foundational instrument for the natural philosopher. He famously designed a clock whose escapement mechanism was based on the pendulum, a device he chose for its timekeeping properties. But an interesting fact is that Galileo used his own pulse as a timing device for establishing that the period of a pendulum's swings is independent from its amplitude, this case suggesting the intimate connection between the intrinsic regularity of natural things and the capacity proper to clocks to model their internal mechanisms. The centrality of these devices for Galileo is already obvious is in his early *Memoranda on Motion* (ca. 1590). There, he mentions the clock and its spring mechanism in order to explain a property crucial for the essence of motions (be they natural and artificial), namely that the forces involved in downward or upward motions do not differ according to these directions [69] (p. 382, trans. Drabkin):

> A mover can impress contrary qualities in the projectile, namely, upward and downward. For the beginning of motion depends on the will, which has the power of moving the arm either upward or downward. And the force that impels an object upward is not different from that which impels it downward. There is the example of the iron spring in a clock which moves [the hands of] the clock up or down, or forward or back, depending on how the clock is turned. Its function is to unwind and straighten itself, just as it is the function of the arm to move the stone away from it.

The centrality of clocks for the development of 16th-century mechanics combined with its allegorical interpretation explains that clocks were employed not only to explain the laws of motions but also to support more general reductionist views of natural phenomena, including sensory properties of the natural world. That Descartes aimed at reducing secondary qualities like colors or smells to mechanical movements of matter is well known. But much less studied is the fact that similar projects were envisioned by different thinkers of the previous century, who already relied on automata like clocks for explaining the sensible properties of experience.

This remarkable point is found for instance in the works of the physician Santorio Santori (1561–1636) who undertook to reduce the motion of animate bodies together with all sensible properties of the natural world to mechanical motions. Santorio Santori, inheriting the developments of the Paduan tradition of philosophy and medicine, offers around 1580 an original theory of matter aiming to reduce all qualities of natural bodies to mechanisms internal to bodies. He relies for doing so on the image of a motion within matter that produces on the senses the various impressions that we call colors, smells, sounds and so on. A striking aspect of Santorio's view, anticipating in several respects the theories of matter and secondary qualities later developed by Descartes and his ilk, is it reliance on the image of clock to describe this intrinsic activity of matter. In his *Methodi vitandorum errorum omnium qui in arte medica contingunt libri XV*, Santorio writes (trans. F. Bigotti in [70]:

> As a final point, we can bring the most evident of all the examples, that is the clockwork moving power (*potentia motrix horologii*) [that produces qualities of the substance]; none in his right senses would argue that the clockwork moving power originates from the temperament, but that it comes from the 'number' (*numerus*), 'position' and 'shape' of its gears, circles and springs [...]. If a human artifex is able to impart many moving virtues by changing the 'shape',

> 'position' and 'number' of the gears, how much more the benevolent Mother Nature, forging the mechanisms and, so to speak, the living springs with greater artifice, will be able to put the moving virtues inside these substances! [. . .].

This passage contains most of the elements that have been listed for explaining the philosophical popularity of clocks compared to other automata. The mention of "Mother Nature", seeming to indicate the remains of teleological elements in Santorio's new philosophy of nature, should not mislead us. The interaction between the internal parts of matter, similar to the gears, circles and springs of a clock, constitutes the real cause of its motion rather than any qualitative principle (i.e., the "temperament"). The clock thus exemplifies the general hypothesis of an intrinsic mechanism proper to the material world that is at the same time the principle of its measurability. What is more, Santorio extends the symbolic function of clocks to give a concrete picture of the reducibility of qualitative aspects of the physical world, that is, these properties that seem the most difficult to explain from a mechanistic standpoint, foreshadowing the most radical reductionist doctrines of the 17th century.

The philosophical history of clocks, as can be seen, went well beyond the definitional puzzles raised by the Aristotelian definition of nature. Increasingly invoked for grounding an interpretation of nature as a sort of machine explainable simply in terms of its material parts and local motion, clocks ended up as symbols for the most extreme versions of mechanical philosophy.

4. Conclusions

The discussions of clocks and automata from the 14th century to the end of 16th century provide evidence that the collapse of the art/nature distinction that we encounter in Francis Bacon, Galileo or Descartes is the final result of a gradual process that took place at the crossroad of different problems and theoretical concerns in the history of philosophy and science. This observation, however, should not hide the real shift of paradigm that eventually took place. By contrast with the general agreement in the Middle Ages on an ontological difference between artifacts and natural beings, there remains no need in the eyes of the great figures of the early 17th century to maintain a distinction between them. Rejecting any essential difference between them, Descartes endorses the same "clockwork universe" as many other 17th-century philosophers—the clock mirrors the regularity of the laws of nature itself [71,72]—but draws radical conclusions from it. The only difference between artifacts and natural beings lies in the size of the mechanisms involved: Whereas the internal mechanisms of artifacts are large enough to be perceivable by us, they are too small in natural beings to be accessible to our senses and, thus, remain more difficult to know from our perspective. As to their essence, however, no distinction exists between the laws governing machines and other technological devices and natural beings, as Descartes writes in the *Principles of Philosophy* [73] (4, p. 209):

> For I do not recognize any difference between artefacts and natural bodies except that the operations of artefacts are for the most part performed by mechanisms which are large enough to be easily perceivable by the senses [. . .]. The effects produced in nature, by contrast, almost always depend on structures which are so minute that they completely elude our senses.

The definitional problems posed by clocks and automata can be viewed as one of many factors of the mechanization of nature. These historical factors are for obvious reasons intimately connected. Yet, following distinct evolutions that were not strictly parallel, they could have occurred to some extent independently from one other. The recovery of the *Problemata mechanica* and the subsequent development of mechanics was not originally connected with the discussions over the reality of artifacts and the definition of nature that historically coincided with the invention of the mechanical clocks. The growing tendency of theoretical medicine for modelling biological functions on technological devices was also largely independent from these earlier discussions. These different aspects of late medieval and early modern thought, without neglecting the influence of other historical and intellectual factors, contributed by their interaction to the eventual collapse of the art/nature distinction. From this respect, they can be considered as concurrent partial causes of the 'mechanization of nature'.

The connections of the philosophical problem of distinguishing nature from art with the development of theoretical mechanics as well as the growing use of technological devices in life sciences and medicine highlight the theoretical importance of automata at the dawn of the Modern era. But they also explain why clocks, much more than any other automatic device, enjoyed such a philosophical fame. As theoretical models, clocks could function better than other automata both as an allegory of mechanism on one level (by representing (1) the regularity of nature and (2) the measurability of natural processes while (3) recalling the idea of a divine craftsman responsible for this harmoniously ordered construction) *and* as a functional analogy for natural processes (because of (4) the cosmological centrality of circular motions, (5) the exemplification of elementary laws of motions in their manufacturing and (6) the alternance of motion and rest legitimizing the clock model also for biological phenomena). These theoretical functions, ranging from the allegorical use to the more concrete empirical analogy, explain that clocks were elected as the favorite symbol of philosophers and scientists willing to ground a mechanistic conception of the universe. We can thus understand the significance of the words of the physician Vopiscus Fortunatus Plemp (1601–1671) when, criticizing the Cartesian mechanical conception of biological functions, he condemns the view according to which muscles are moved "*horologialiter*" [74] (p. 247a).

The notion of mechanism and the real scope of mechanistic explanations are notoriously subject to debate (for a recent overview, see [22]). Admittedly, this notion evolved and served to designate in the late Middle Ages and early modern period different types of intellectual projects, including a transitional phase during which pieces of mechanistic explanations were integrated into an overall teleological conception of the universe before the full-fledged versions of mechanical philosophy found in the 17th century. One of the lowest common denominators of mechanistic doctrines, however, was the use of practical and theoretical mechanics to explain the course of nature. In her work on mechanism in Ancient philosophy, Sylvia Berryman suggested that the general distrust of ancient philosophers toward mechanism was the lack of devices and automata able to back up the claim that the universe was indeed to be understood as a type of machine [75]. As the discussions led in the period 1300–1600 show, the historical event represented by the invention of mechanical clocks in the late Middle Ages may have been a decisive factor for changing philosophers and scientists' mind on this point.

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Notes

1 For a recent overview of the debates concerning the applicability of this category in the history of early modern science as well as its relevance for contemporary philosophy of science, see [22] (esp. pp. 15–39) and the references therein.

2 On the two formulations of this criterion and their possible interpretations, see [25] and the references therein.

3 [28] p. 250, ll. 12–14: "Et horologium artificialiter habet in se principium sui motus localis et candela similiter principium suae combustionis lichini." Unless otherwise noted, translations are mine.

4 [32] f. 20v: "[. . .] che la sforzi à mover contra natura, come (per essempio) nell'orologio, il peso od altra simil forza che muove la ruto principale, vien per la gravezza sua, come per sua natura [. . .]."

5 [31] II, f. 19va: "Artificialia vero inquantum artificialia non habent in se principium passivum inclinans ad talem incisionem vel talem erectionem, nec habent aliquod per artem per quod sint susceptiva vel per quod inclinentur ad talem motum sive habeant aliquod quod sit causa talis motus sive non."

6 [37] II, f. 136a: "Et haec tertia resolutio magis verbis Aristotelis convenire videtur [. . .] cum dixisset artificialia, non quo sunt artificialia, intra se motus principium includere, sed quo lapidea, aut terrea [. . .]."

7 [38] II, q. 2, ff. 87–88: "Nam si fiat figurae planae causabit in artificiato motum rectum, et non circularem nisi cum difficultate, si autem fiat figura pyramidalis, aut sphericae inclinabitur ex tali figura ad motum sphaericum, ergo etc. [. . .] Ut igitur dissolvas utraque dubietatem, adverte quantum ad primam partem, quod est aliud habere in se principium motus, et habere in se principium qualitatis, aut modi motus. Nam primum convenit soli formae naturali, puta quod terra aut lapis moveatur deorsum convenit eis, quia habent gravitatem, quae est qualitas naturalis. Unde quaecunque figura imprimatur in terra vel in lapide, nisi adsit gravitas, nunquam movebitur motu naturali deorsum."

8 [42] (II, c. 7, q. 19, 394–395: "Nam cum figura nihil aliud sit, quam modus quantitatis et quantitas, ut saepe diximus omnis activitatis expers sit, utpote quae se habeat ex parte materiae, consequens est ut agendi vi careat. Nec obstat, quod acuta corpora, caeteris paribus, per aquam velocius descendunt. Non enim id ex eo provenit, quod acumen active influat ad motum [. . .]. Lege etiam, quae in eandem sententiam scripsit Aristoteles in Mechanicis, ad eam quaestionem, cuius initium est: 'Cur est figurarum genere, quaecunque rotundae sunt et circinatae, etc'." Let us note the interesting reference to the *Problemata mechanica* in this passage.

9 [43] d. 18, sect. 4, 8–9, ff. 626b–627a: "Ratio autem est quia figura, ut sumitur etiam ex Aristotele, lib. I Phys., c. 5, text. 46, nihil rei addit quamdam compositionem aut ordinem partium, ex quo consurgit modus quidam quantitatis, qui est figura, et ideo non potest esse principium per se agendi, tum quia tantum est quidam modus, tum etiam quia est modus quantitatis et proprietas consequens illam. Unde, cum quantitas per se activa non sit, neque figura esse potest. [. . .] figuras solum esse dispositiones ex parte instrumenti aut corporis ut facilius tali modo moveatur vel moveat, vel quia ipsum minus resistit dum ab artifice movetur, ut in motu sphaerae, vel quia ei minus resistitur, ut in motu incisionis; nam quo instrumentum est acutius, eo pauciores partes contingit, et ideo minorem resistentiam invenit."

10 [47] II, f. 310: "Conatur tamen Simplicius tueri Alexandrum, et dicit quod si bene confideremus, discrimen est inter naturalia et artificialia penes partes essentiales, nam res naturales habent partes essentiales naturales, si non remotas, saltem propinquas, videlicet, quatuor elementa, sed artificialia nullas essentiales partes habent artificiales, sed omnes naturales tam propinquas, quam remotas, quare Aristoteles recte dixit, (et horum partes) ad differentiam artificialium. Contra hanc expositionem Alexandri et Simplici Pendasius instat dicens, si hoc modo intelligeretur Aristoteles, esset superfluum, quia his nominaret elementa inter corpora naturalia, si per partes animalium intellexit ipsa elementa. Addit autem posse defendi alio modo expositionem Alexandri, exponendo de partibus inte-grantibus, nam omnes illae partes, quae sunt actu in toto, et in quas totum actu dividitur, dicuntur integrantes, et sic partes artificialium integrantes sunt naturales, neque sunt necessario artificiales, naturalium autem necessario sunt naturales. Hanc putat esse ex-positionem Alexandri, ut revera est, quae etiam Themistii fuit; sed neque haec expositio ei placet, quia dicit, si Alexandri expositio admitteretur, quod Aristoteles dixisset (et harum partes) ad differentiam artificialium, debuisset dicere etiam de plantis et elementis (et partes ipsorum) non enim animalibus solum id competit ad differentiam artificialium, sed omnibus naturalibus ut partes habeant necessario naturales."

11 [47] II, f. 312: "[. . .] Ideo advertendum quod differentia inter naturalia et artificialia non in eo est constituta, quod naturalia habeant in se principium motus, non naturalia vero non habeant; immo cum omnia haec sint corpora necesse est, ut omnia habeant in se principium motus, sed differentia est ista, quod naturalia habeant in seipsis principium motus per se, id est, quatenus sunt talia; non naturalia vero habent quidem principium motus in se, non tamen per se, sed per accidens, quia non quatenus talia, id est, artificialia [. . .]."

12 [47] I, f. 227: "Et quia in his quinque modis Aristoteles nominabit aliquos, qui sunt artificiales, dicit Simplicius, quod generatio simpliciter dicta, convenit etiam artefactis, quamvis enim artificialia sint accidentia, tamen dant novum nomen et novam definitionem, et sunt loco formae substantialis. Figura enim statuae est veluit forma substantialis, et habet rationem formae dantis esse respectu statuae, unde est, quod secundum appellationis figuram dicuntur artefacta simpliciter fieri, sine ulla additione, non fieri aliquid, dicimus enim, domus fit, statua fit, quod vocatur simpliciter fieri."

13 [54] f. 111ra: "Ideo Aristoteles satis declaravit de ea quomodo concurrat, quemadmodum declaravit principia motus ex parte animae, vult declarare ea ex parte corporis, et quia res est difficilis, recurrit ad exempla, et dicit quod similis est motus animalium motui locali multarum machinarum cum moventur, una pars movet alteram, sicut fiunt istae machinae spontanae quae ex se moventur in motu horologii [. . .]. Secundo sicut in motu illorum una pars movet aliam sicut in horologio, etiam in motu currus rotae maiores moventur, minores vero quiescunt, vel si non simpliciter quiescunt, videntur tamen quiescere, quia non tanta velocitate moventur sicut in motu animalis, quia una pars aliam impellit, quia calor movet nervos, nervi musculos, et si consequenter una pars quiescit in motu alterius, quia una pars movet alteram, sicut deambulamus movendo pedem dextrum innitimur pedi sinistro, est alia similitudo, quia ferrum est in curru, et machinae et funes sicut sunt ossa et nervi in animali, tunc apparet similitudo in motu machinae et currus et animalis [. . .]."

14 [58] p. 293, n. 7: "Est igitur omnino in operibus quidem naturae ars mechanica, quam diligenta animadversione talium operum maxima solertia artique sapientes adinvenerunt, quamque etiam non haberemus si naturalis non esset."

15 Let us note that as early as the late 14th century, Blasius of Parma (ca. 1350–1416) included in his *Questions on the Physics* a problem (i.e. a question written in the style of *problemata*) involving scales and the "science of weights" in his discussion of the ontological status of artifacts ([64] (II, q. 1, ff. 84vb–85ra)). The connection between the problem and the question about artifacts in which it appears, however, remains puzzling and one can only speculate about the function of this particular problem in the question.

16 [68] p. 249, trans. Drake: "Windmills, watermills, mills turned by living beings, wagons, plows, and other farm devices are reducible to mechanics. So are the weighing of things with balances, the drawing of water from wells by pulleys or by cranes, called in Latin tollenones, which are like huge balances. The manner of conducting water and raising it from deep valleys to heights is similarly derived. The ancients called those persons mechanics also who produced miraculous effects by means of wind, water, or ropes—such as various sounds, or songs of angels, and even the expression of words as by human voices; and those who made clocks which were run by wheels or by water or which measured time by means of the sun and distinguished the hours. Mechanics are those who make celestial spheres showing the various heavens and the movements of the planets and other heavenly bodies like a miniature universe, by the equal movement in rotation given by water power, as we are told was done by Archimedes of Syracuse, the first master."

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