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(*b*. Pesaro, Italy, 11 January 1545, *d*. Pesaro, 6 January 1607),

mechanics, perspective, astronomy, mathematics. For the original article on Guidobaldo del Monte see *DSB*, vol. 9.

Guidobaldo has often been viewed as a minor figure in the history of mechanics; Duhem described him as "sometimes in error, always mediocre" (Van Dyck, p. 373). Recent research has delved into his writings in greater detail and revealed his frequently ingenious approaches to contemporary problems in physical science and elucidated the historical importance of his work on perspective. This article is divided into two parts. The first emphasizes his work in mechanics and cosmology; the second deals primarily with his writings on perspective.

Mechanics . "Mechanics is no longer mechanics if it is separated from machines"; in current terms mechanics deals with *constrained material systems*. This is the program that Guidobaldo announces in the preface to his *Mechanicorum Liber* (Treatise on Mechanics), in which machines are the five simple machines of ancient engineering tradition, namely, the lever, the pulley, the wheel and axle, the wedge, and the screw.

The *Mechanicorum Liber* gives the appearance of an unbalanced text because 80 percent of its pages deal solely with levers and pulleys; this circumstance can be explained by the fact that Guidobaldo performed many experiments with levers and pulleys, constructing for this purpose true experimental apparatuses: special pulley systems "that turned with a puff of air," equal-armed levers with coinciding centers of gravity and points of suspension. For this particular type of lever Guidobaldo anticipates neutral equilibrium, and he demonstrates it on the grounds that whatever may be the position of the lever, the center of gravity always remains at the same height.

This subject occasioned a debate between Guidobaldo on one side and, on the other, Giordano, Niccolò Tartaglia, and Girolamo Cardano, who denied the state of neutral equilibrium and maintained that the lever would return spontaneously to the horizontal position. The dispute is a good example of scientific "rhetoric" in that Guidobaldo turns his opponents' own arguments against them. For example, in order for the lever to return spontaneously to the horizontal position, the highest part of the lever must "gravitate" more than the lower part, but this implies a displacement of the center of gravity, which is absurd because the position of the center of gravity does not change according to the inclination of the bodies. Therefore it is not true, as is commonly stated, that for Guidobaldo one must take into account the convergence of the weights on the balance toward the center of Earth: his thesis appears only as a rhetorical device in this dispute on equilibrium, and in fact Guidobaldo does not take it into account when he studies the problem in the early propositions of the *Mechanicorum Liber*. Guidobaldo shows that the properties of simple machines are reducible to the properties of the lever. For these simple machines he describes the relations among the weights, hoisting heights of the weights, the time elapsed, and the velocity, along with a physical magnitude that he calls variously "stress," "power," or "force," which in any case indicates something capable of producing or inhibiting the motion of a mechanical system. Guidobaldo enunciates a principle that in current terms can be expressed thus: in machines there is no saving of labor. From his technical experiments Guidobaldo extracted important data such as the clear identification of *string tension* and of the *constrained reaction of the supports* that govern the pulley systems.

One should note the parallel sociocultural action, so to speak, that Guidobaldo undertakes. First, on the philosophical plane, he joins the debate about the relation between art and nature; he shows clearly that machines neither deceive nor surpass nature, but they produce the same effects that nature itself would produce under the same conditions. Second, following the line of thought begun by his mentor Federico Commandino, Guidobaldo continues in the work of reestimation of both theoretical and applied mathematical disciplines within a cultural context that traditionally privileged philosophical, theological, juridical, and medical studies. Thus, Guidobaldo promotes mechanical science around the idea of a broad and highly esteemed presence of machines in the ancient world. He exalts as great "mechanicians" Hero of Alexandria, Ctesibius of Alexandria, and Pappus of Alexandria, and he contests Plato's criticisms of Eudoxus of Cnidus and Archytas of Tarentum for their conceptions of mechanics, which were more applicative than speculative. The highest place of all is occupied by Archimedes, regarded as the ideal figure of the technologist capable of fusing theory with practice, speculation with action.

As far as mechanics is concerned, Guidobaldo perceives an absolute continuity between Aristotle and Archimedes. The Aristotle that he examines is the Aristotle of the *Mechanical Problems*, in which Guidobaldo claims to have found in implicit form principles that Archimedes later formulated in a rigorous manner. His appreciation of Aristotle is not simply formal; the *Mechanicorum* contains not only the Archimedean approach to problems, which considers weights, centers of gravity, and distances from the fulcrum, but also the Aristotelean approach, which deals with weights, displacements, and "virtual" velocities, which today we would call the static and dynamic aspects of mechanics.

The above-mentioned debate over the neutral equilibrium of the lever, besides its polemic purposes, assumed for Guidobaldo a theoretical importance. In the context of his studies, the neutral equilibrium marks the delicate passage from immobility to movement. In machines, says Guidobaldo, the disruption of equilibrium, or rather the passage from supporting weights to moving them, occurs when the relation between resistance and power becomes less than the relation between the "virtual" displacement of power and that of resistance. But how much less? Guidobaldo speaks of this in a letter written in 1580 to Giacomo Contarini (1536–1595), a Venetian patrician and an expert in fortifications. Guidobaldo concludes that "matter creates some resistance" when weights move, not when they are supported.

The first printed text on mechanics, the *Mechanicorum Liber* was a great success as evidenced by its translation into Italian four years later, which indicated an active interest on the part of technicians who did not know Latin but who needed to understand the principles of their end products in order to be able to improve them.

Cosmology . In the writings of Guidobaldo the subject of cosmology occupies a somewhat secondary position, which is in keeping with the general orientation of the scientific environment in Urbino, where there was scant interest in such questions. Guidobaldo, however, finds it natural to accept the geocentric image of the universe and he justifies it mechanically. In his commentary on the *Equiponderanti* (*Plane Equilibrium*) of Archimedes he establishes that the Earth, since it is a sphere, has a single center that exhibits both the geometric properties of symmetry and the mechanical properties of the center of gravity. Since according to Aristotle the Earth lies at the center of the universe, the center of gravity will also be at that point. To the objection that the Earth is formed of water and earth, "elements" that have different specific gravities, Guidobaldo responds by citing a proposition in *On Floating Bodies* in which Archimedes demonstrates that the surface of the waters has a spherical form with its center coincident with the center of the Earth. In a page of the *Meditatiunculae* (Little Meditations) he again approaches the question from a mechanical point of view; in fact, he recognizes that the displacement of bodies on the surface of the Earth makes the distribution of weights change, thus causing a displacement of the terrestrial center of gravity and consequently of the entire Earth, an old idea that can be found in Giovanni Buridano. Guidobaldo's booklet *De Motu Terrae* (Concerning the Earth's Motion) has been lost, but given these presuppositions it probably did not contain any different ideas.

The *Problemi astronomici* (Problems of Astronomy), published posthumously by his son Orazio, is a text dedicated exclusively to mathematical astronomy; not even in the chapter on comets does Guidobaldo give any opinions on the terrestrial or celestial nature of those bodies.

He was, however, compelled to speak out in 1604, when there appeared a supernova that called into question the physical doctrine that the heavens are incorruptible. The easiest solution was to classify it as a comet, but unlike comets, the supernova did not show an inherent movement with respect to the fixed stars. This fact was indeed confirmed by Johannes Kepler's observations, which were known to Guidobaldo very probably through Father Christopher Clavius. Guidobaldo accepted these observations insofar as they conformed to his own. Nevertheless, he remained in doubt about the star-comet alternative and was unable to decide whether the heavens could be "corruptible."

Guidobaldo on Perspective . In 1600 Guidobaldo published *Perspectivae Libri Sex* (Six Books on Perspective), which became a turning point in the history of the mathematical theory of perspective. Before Guidobaldo, Commandino, Egnazio Danti, and Giovanni Battista Benedetti had sought to understand the geometry behind perspective, and they had been successful in proving the correctness of certain perspective constructions. Guidobaldo, however, took a different approach, in which he based his considerations on general geometrical laws. He was the first to realize the importance of the perspective images of sets of parallel lines as the basis of constructions, and he created the concept of a general vanishing point. His accomplishments were so fruitful that it is appropriate to designate him the father of the mathematical theory of perspective.

Guidobaldo's inspiration to take up perspective most likely came from his teacher Commandino. Thus, of the two manuscripts on perspective that Guidobaldo left— presumably dating from the period 1588–1592—the oldest one reflects many of Commandino's ideas. The younger one, by contrast, contains new ideas that resulted in Guidobaldo's innovative treatment of perspective.

Before Guidobaldo, it was common knowledge among mathematicians and practitioners of perspective that the images of lines perpendicular to the picture plane converge in one point—later called the principal vanishing point—which is the orthogonal projection of the eye point upon the picture plane. Similarly, some writers were aware that the images of horizontal lines forming an angle of 45° with the picture plane converge at a point on the horizon—later called a distance point. Guidobaldo realized, and proved, that the images of a set of parallel lines that cut the picture plane ϕ (Figure 1) all meet in a point, say V, which he called their *punctum concursus*. He proved that this convergence point, later called a vanishing point, is the point of intersection of the picture plane and the line among the parallel lines that passes through the eye point O. This insight gave Guidobaldo a means to determine the image of a line l that cuts the picture plane in a point A (Figure 1): Since the point A is situated in the picture plane it is its own image and hence lies on the image of l; furthermore the image of l, prolonged, passes through its vanishing point V; in other words the image of l is determined by the points A and V.

From the image of a line, Guidobaldo turned to determining the image of a given point; he did this by constructing the images of two lines passing through the given point. He was so taken by this possibility that he presented no fewer than twenty-three different methods of constructing the image of a point.

All Guidobaldo's successors took over his concept of a vanishing point either directly from his work or from some of the authors inspired by him, among whom Simon Stevin and Samuel Marolois presumably were the most influential. A great part of the further development of the theory of perspective consisted of generalizations of Guidobaldo's ideas. Thus, later mathematicians introduced the concept of a vanishing line for a set of parallel planes cutting the picture plane. This line consists of the vanishing points of all the lines in the parallel planes—the horizon being a noticeable example of a vanishing line, namely of horizontal planes. Guidobaldo did not single out the concept of a vanishing line, but it occurs implicitly in his work. After Guidobaldo, inverse problems of perspective caught the interest of several of the leading mathematicians in the field of geometrical perspective. Guidobaldo had also touched on this topic, and he opened up a few other topics.

It is impressive how much Guidobaldo obtained by combining classical Greek geometry with his concept of vanishing points. His style of presentation, however, is remarkably inept because he included a lot of unnecessary theorems (for more details on *Perspectivae Libri Sex*, see Andersen, 2007).

Guidobaldo on Euclid and Proportions . As Paul Lawrence Rose wrote in the original *DSB* article, three manuscripts by Guidobaldo on proportions and on Euclid's *Elements* have been identified; however, at present the locations of only two of them are known. Guidobaldo's work on the theory of proportion, and in particular his generalization of Euclid's concept of composition of ratios, were treated by some scholars at the end of the last century.

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