

BALESTRA AND THE PYTHAGOREAN METHODOLOGY OF GALILEO AND DESCARTES

BY way of introduction, I am pleased to say that, as a basis on which to make the following comments, I am the fortunate beneficiary of the relevant work of Richard Blackwell in the form of both the content of his graduate seminars and in his published research. Prof. Blackwell was my graduate advisor and much admired teacher for a number of courses. My first published papers, papers on Peirce, Kuhn, Piaget, and — especially relevant here — papers on Galileo's method¹ came directly from seminars taught by Prof. Blackwell. I have said facetiously in moments of frustration that the drive to philosophize — to seek to know and answer the fundamental questions — is a 'divine madness' from which we would all do better to be cured. It is my experience of the living scholarship and teaching of a few paradigm philosophers such as Richard Blackwell that re-inspire my own efforts. I join the participants of this conference in honoring a man whose scholarship, teaching, and genuine concern for students is exemplary and a model for all of us who would be philosophers and teachers.

There are a number of interesting points raised by Prof. Balestra² that are worthy of comment, though for brevity I will focus on only the main issue of how to interpret the significance of the 'Pythagorean method' of Galileo and Descartes. The advocacy and adoption of this methodology, rightly understood, is central, I propose, to the rationality of the seventeenth century scientific revolution, and to the core of what should be included under Balestra's term of demythologized Pythagoreanism. This core is, in brief, the promotion of *structural explanations* and the integral and natural role of mathematics therein. For, what ought to be implied by the assertion that Galileo's and Descartes's 'Pythagoreanism' is a philosophy of nature is, in regard to its lasting legacy to the history of science, not an ontology of mathematics-incarnate (mathematical entities — numbers, geometric figures — as actual constituents of physical reality), but rather a methodology for generating the distinct type of explanation we call *structural*. A paradigm example of such an explanation is Galileo's Copernican argument from the tides, the example Balestra focuses on.³ Such explanations are inherently impossible for the Aristotelian essentialism of monadic properties and

concomitant syllogistic logic, the then-canonical rival to the mathematical physics of Galileo and Descartes. I propose that it was not Descartes's argument in the *Meditations* that in either a theoretical or practical sense dislodged the grip of an Aristotelian theory of nature in favor of mathematical physics, as Balestra argues, but rather it was the practical explanatory and discovery power of structural explanations, aided by the gradual acceptance of the practical impossibility of establishing demonstrative certainty in physical matters (acknowledged, for example, by Christiaan Huygens).

In the polemics with their rivals, both Galileo and Descartes maintained the ideal of demonstrative certainty for scientific results, and this would have been prerequisite for getting a hearing within the then orthodox scientific/philosophic community. Yet, in practice both Galileo and Descartes accepted as established many scientific explanations that were less than certain, explanations which are characterized at places by Galileo as "very little lower than mathematical proof"⁴ and by Descartes as "morally certain" (as opposed to metaphysically certain).⁵ The physico-mathematical explanations offered by Galileo and Descartes (and indeed those of modern science generally) do not need a 'realistically' construed mathematics, realistic in the sense of actual placing mathematical entities in material nature, in order to provide veridical explanations making ontological claims. Structural explanations make ontological claims about the posited physical structures, i.e., the network of posited relations (causal/temporal/spatial), that given physical and/or mathematical structures model, a modeling warranted by observational verification. Internal essences of isolated single substances and their properties are not the focus here, but rather the polyadic relations that otherwise unknown subjects enter into with other such subjects in the thus explanatory network. Based in part upon his rejection of explanations in terms of essences, I

⁴Donald Mertz, "On Galileo's Method of Causal Proportionality," *Studies in the History and Philosophy of Science* 11 (1980): 229-242, and "The Concept of Structure in Galileo: Its Role in the Methods of Proportionality and *Ex Suppositione* as Applied to the Tides," *Ibid.* 13 (1982): 11-131.

⁵Dominic Balestra, "At the Origins of Modern Science: Demythologizing Pythagoreanism" in this volume.

⁶For an analysis of Galileo's use of structural arguments, especially for the Copernican motion of the earth, see Mertz, "On Galileo's Method" on "The Concept of Structure."

⁷Galileo, *Dialogue Concerning the Two Chief World Systems*, trans. Stillman Drake (Berkeley: University of California Press, 1967), 408.

⁸René Descartes, *The Philosophical Writings of Descartes*, vol. I & II, trans. J.

Cottingham, R. Stoothoff, & D. Murdoch (Cambridge: Cambridge University Press, 1985), Vol. III trans. Cottingham, Stoothoff, Murdoch, and A. Kenny (Cambridge: Cambridge University Press, 1991), I:289f. Hereafter abbreviated PW.

⁹Galileo, *Discoveries and Opinions of Galileo*, trans. Stillman Drake (New York: Doubleday, 1957), 237-238.

¹⁰For the claim that Galileo did not hold a mathematical ontology see Gary Hatfield, "Metaphysics and the New Science," in *Reappraisals of the Scientific Revolution*, ed. D. Lindberg and R. Westman (Cambridge: Cambridge University Press, 1990), 93-166.

¹¹Richard J. Blackwell, "Descartes' Concept of Matter" in *The Concept of Matter in Modern Philosophy*, ed. Ernan McMullin (Notre Dame: University of Notre Dame Press, 1978), 59-75. ¹²PW.I. 210ff.

would propose that this is how we best understand Galileo's conception of the role of mathematics in physics. When he says that nature is written in the language of mathematics where its characters are triangles, circles, etc. we should understand this in a straight forward manner as saying that these geometric figures are the *characters* — the alphabet — of the language describing nature, but not as such part of the nature described.⁶ Galileo did not subscribe to mathematical essentialism.⁷

In contrast to Galileo, Descartes did think it necessary to have a metaphysics of mathematical physics, one that identified the essence of material nature with *extension*. This was mathematics — or specifically, geometry-incarnate — and thus Descartes held to a geometric essentialism — a "demythologized Pythagoreanism." Conforming to the prevailing Aristotelian canons for proper physical explanation that required this be in terms of statements of essences of physical subjects, Descartes's essentialism made it possible for him to pose physical problems mathematically and to treat results as physics and not irrelevant pure mathematics. So *contra* Balestra, in so construing geometry Descartes remains under the grip of Aristotelian meta-theory.

Descartes's physics was continuous with his metaphysics which remained in essential ways Aristotelian, and this was a source of considerable weakness. A particular weakness is the thesis that all attributes of material entities — motion, rest, plurality, weight, resistance, shape, figure, etc. — are modes of extension. However, to carry out his reduction, Descartes needs motion as a principle co-equal with extension, and indeed he must rely upon motion more than extension in order to generate the observed primary qualities of things. As Blackwell observes,⁸ the unequal burden on motion over extension, and the dual status of motion as both a mode of extended substance and as a coequal principle for generating the universe, are indictments of Cartesian metaphysical/geometrical physics. Despite the fact that Descartes rejects explanations in terms of substantial forms and in their place promotes structural theories, he nevertheless retains an Aristotelian-like ontology of substance, attribute, and mode, as laid out in the *Principles of Philosophy* (1644).⁹ It is strange from the perspective of this schema that, as Blackwell observes, Descartes treated extension as a monadic property. Not only would one expect extension to be treated as an underlying subject substance rather than as a predicate of what would then apparently be an incoherent "bare particular," but there is also the problem of how specific multi-subject spatial relations can be generated from the generic monadic property of extension. *Pace* Descartes, extension is a dependent, secondary attribute of an entity, one whose predication is based upon the logically prior obtaining of specific spatial

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relations between distinguishable parts of the entity. Descartes inverted this dependency in an attempt at what is a failed essentialism, a physics that was excessively geometric at the expense of physical concepts.

Whether it was perceived at the time as failed or not, Descartes' extensional metaphysics did not succeed in dislodging the grip of an Aristotelian theory of nature, as Balestra holds, but rather it was the practical success of the method of structural explanation. Conforming to Balestra's apt injunction, I shall below briefly "recontextualize" the use of structural explanations in the works of Galileo and Descartes.

Central to the concept of rationality in natural science is the achievement of an effective methodology for providing explanations of physical phenomena. Characterizing the 'modern' methods of Galileo and Descartes, they have been described as proper mixtures of mathematics and physical observation/experimentation. Both Galileo and Descartes saw themselves as rejecting the traditional method of unaided/uncontrived observation plus syllogistic logic for a more potent method synthesizing experimentation and mathematics in a broad sense of what we would call structural modeling. Both men reject appeal to forms and qualities of the Aristotelian/scholastic tradition as non-explanatory. Galileo describes the attempt to know of such properties as an "impossible undertaking,"¹⁰ and Descartes holds that "no one has ever succeeded in deriving any practical benefit from 'prime matter', 'substantial forms', 'occult qualities', and the like."¹¹ Syllogistic logic is also rejected because, as Galileo puts it, "though much preached [logic] is not very powerful."¹² Descartes agrees, saying "with regard to logic that syllogisms and most of its other techniques are of less use for learning things than for explaining to others the things one already knows."¹³ For both Galileo and Descartes, syllogistic logic is to be rejected because it is not a tool for gaining new knowledge — it is not a 'logic of discovery'. The supposed intellectual power of 'quickness of wit' (*achinoia*), the gift Aristotle said humans have for hitting upon causal middle terms in demonstrative syllogisms, is here rejected as ineffectual. The true and efficacious logic of discovery for physics is applied mathematics; geometry for Galileo; geometry (specifically, the geometric diagram)¹⁴ assisted by algebra for Descartes. Galileo has Simplicio say "Truly I begin to understand that although logic is a very excellent instrument to govern our reasoning, it does not compare with the sharpness of geometry in awakening the mind to discovery (*invenzione*)."¹⁵ And Descartes in a letter of 1648 asserts, "A study of mathematics, then, is a prerequisite for making new discoveries, both in mathematics itself and in philosophy."¹⁶ In short, both Galileo and Descartes

are transitional figures who retained as an ideal of scientific explanation the residual Aristotelian standard of demonstrative certainty, and this no doubt reinforced the appropriateness of adopting mathematics as an explanatory tool, a thesis debated at the time as non-Aristotelian. Yet, what equally appealed to both Galileo and Descartes was the power of applied mathematics as an instrument of discovery. And it is, I contend, that aspect of the nature of applied mathematics which empowers it as an instrument for extending our explanatory knowledge that is the lasting legacy of Galileo's and Descartes's contribution to the seventeenth century scientific revolution.

Now, what is it about the nature of applied mathematics that makes it a tool for gaining new insights and explanations of natural phenomenon? To answer this, it must be understood that applied mathematics is a component of the broader category of *structural explanations*, specifically, explanations in terms of *structural isomorphism* or modelings. Stated precisely, a structural explanation consists in a partial isomorphism between two parallel structures or complexes, one a given physical and/or mathematical structure or model and the other a hypothesized structure held to effect some given phenomena. In causal explanations, the connecting mapping that is the isomorphism rests on the principle of similar effects having similar causes. The promotion of structural explanations is a pivotal element of the seventeenth century scientific revolution, as fundamental, if not more so, than the increased emphasis on active experimentation. To use an analogy from modern logic, while experimentation provides the semantical content for scientific explanations, the structural form provides the formation and transformation rules, and because of the latter the potential for the retroductive introduction of conceptual novelty. What makes partial isomorphisms between paralleling structures a 'logic of discovery' is that properties and relations revealed by the examination of the given structure suggest analogous properties and relations in the hypothesized structure. It may be possible that these new hypothesized attributes are verified directly and singly by experiments, or they may be warranted only holistically on how well they hold together with other attributes that are more directly verified. In the *Principles*, after using the example of a structural explanation of the decoding of an encrypted letter, Descartes asserts of his theories of "magnetism, fire and the fabric of the entire world" that "even if they think that my assumptions of these principles was arbitrary and groundless, they will still perhaps acknowledge that it would hardly have been possible for so many items to fit into a coherent pattern if the original principles had been false."¹⁷ Here we have coherence as the warrant for a retroductive form of the hypothetico-deductive method.

¹⁰Quoted in Stillman Drake, *Galileo at Work* (Chicago: University of Chicago Press, 1978), 199.

¹¹PW,III:221.

¹²Galileo, *Dialogue*, 191.

¹³PW,I:119.

¹⁴PW,I:57II & 67II.

¹⁵Galileo, *Two New Sciences*, trans. Stillman Drake (Madison: University of Wisconsin Press, 1974), 133.

¹⁶PW,III:351.

¹⁷PW,I:290.

Before touching further upon the role of structural explanations in the works of Galileo and Descartes, it is important to observe that the role and power of structural explanations in the history of science have not been sufficiently appreciated. Two exceptions to this can be found in works of Ernan McMullin and Richard Blackwell. McMullin has pointed out that there are three broad categories of explanations found within the natural sciences: nomological, genetic (i.e., historical development), and structural, with the latter receiving surprisingly little attention.¹⁸ Yet, McMullin observes that structural explanations are more powerful than the other two types, because they warrant ontological claims about unobserved processes, and they make for correct prediction and technical control. A good structural model provides resources for imaginative extension for some time after its introduction. Now, these same three categories of explanation can be seen at work at the meta-level of philosophy of science — in the theories, respectively, of logical empiricism, the Kuhnian theory of revolutionary paradigm shifts, and in a structuralist-Piagetian account. Blackwell holds that the direct object of epistemological analysis is structure, where the essential constituents are the interconnecting relations, the “transformation.”¹⁹ These transformations can be dynamic (an event structure such as a complex system of cause and effect) or static (a formal logical or mathematical structure). Blackwell argues that scientific theories grow out of the cognitive activity of problem solving and that they are dynamic structures in Piaget’s sense — self-regulated structures with the functional invariants of organization, equilibration, assimilation, accommodation, and re-equilibration. If we understand this properly, we have the possibility of a rational logic of discovery, something that neither the logical empiricist nor Kuhnian theories can provide. These theses bear on the issue of rationality of scientific change raised by Balestra in his introduction. Blackwell’s adaptation theory provides a non-‘Whiggish’ account of the rationality of scientific change.

Returning to Galileo and Descartes, Galileo did not acknowledge structural explanations as an explicitly recognized category, though his practice is one of using ‘proportional reasoning’ in the extended sense of isomorphic correlation between structures. This was for him a standard mode of explanation, including in his argument for the tides from the Copernican motion of the earth. Descartes, on the other hand, was explicit in attributing to models and ‘analogies’ a *sine qua*

non power of explanation. In a 1638 letter to Morin he states, “I maintain, therefore, that analogies of this sort are the most appropriate means available to the human mind for laying bare the truth in problems of physics. I would go so far as to say that, when someone makes an assertion concerning nature which cannot be explained by any such analogy, I think I have demonstrative knowledge that the point is false.”²⁰ In this regard, Desmond Clarke comments that it is no exaggeration to say that Descartes’s entire scientific project is one of imaginatively constructing models descriptive of motions intended to explain natural phenomena.²¹ Descartes’s strategy is to construct large-scale models that duplicate the hypothesized underlying micro-structure. The assumption is that the general structure and laws of matter apply to all levels of matter, macro- and microscopic.

For Galileo and Descartes, structural explanations are sometimes in concrete terms of material and efficient causes described mechanistically, as in Galileo’s sloshing-water/moving-barge model for the Mediterranean-tides/Copernican-motion of the earth, or Descartes’s tennis ball model for deducing Snell’s law of refraction. Descartes’s general theory of vortices is a structural explanation. Other explanations are in the more abstract terms of comparisons between geometric continua and paralleling continua of spatial and temporal points of composing posited trajectories of hypothesized moving bodies. Examples of this include Galileo’s derivation of the law of falling bodies in the *Two New Sciences*,²² or, specifically in the case of Descartes, the structural parallel between the solution sets of algebraic equations and geometric figures, and the latter with the ultimate subject matter of physics — extended substance. Appropriate here is an observation made by Koyré, and re-emphasized by Blackwell, that Descartes’s conception of motion is a static geometrical idealization consisting in the trajectory of a moving body, not the dynamic change of place itself. This static conception of motion is exactly what one would expect when motion is defined as a mode of extension as with Descartes.²³

A final but crucial point needs to be made concerning why mathematics is congenial to structural explanations. A structure is by definition a network or system of interrelated elements where the *intra*-connecting relations are the essential elements, the natures of the connected nodes serving the role of bases for these relations. Indeed, the natures of the connected elements may be in themselves unknown; it is sufficient for a structural explanation that we know only their relations to other nodes within the system. In this regard, there is an interesting assertion by Galileo,

“In our speculating we either seek to penetrate the true and internal essence of natural substances or content ourselves with a knowledge of

¹⁸Ernan McMullin, “Structural Explanations,” *American Philosophical Quarterly* 15 (1978): 139–147.

¹⁹Richard J. Blackwell, “A Structuralist Account of Scientific Theories,” *International Philosophical Quarterly* 16 (1976): 263–274. Also see “Scientific Discovery and the Laws of Logic,” *New Scholasticism* 50 (1976): 333–344.

²⁰PW, III:122.

²¹Desmond Clarke, *Descartes’ Philosophy of*

Science (University Park: Pennsylvania State University Press, 1982), 124.

²²Galileo, *Two New Sciences*, 169.

²³A. Koyré, “Galilée et La Loi D’Inertie,” in *Études Galiléennes* (Paris: Hermann, 1939), III, 162ff. Also see Blackwell, “Descartes’ Concept of Matter,” in *The Concept of Matter*, ed. Ernan McMullin (Notre Dame: University of Notre Dame Press, 1978), 69.

some of their properties. The former I hold to be as impossible an undertaking with regard to the closest elemental substances as with the more remote celestial things . . . But if what we wish to fix in our minds is the apprehension of some properties of things, then it seems to me that we need not despair of our ability to acquire this respecting distant bodies just as well as those close at hand. . . [These properties are] location, motion, shape, size, opacity, mutability, generation, and dissolution."²⁴

Note that each one of the latter are relational/structural properties. What makes mathematics congenial to structural explanations is the fact that the underlying logic of mathematical systems is a relational logic — a logic of polyadic predicates. This is in contrast to the monadic, subject/predicate logic of Aristotle. Moreover, as we now know, it is impossible to reduce the logic of relations to the logic of properties.²⁵ It is interesting to note that scholars of the sixteenth and seventeenth centuries (including Christopher Clavius) attempted to demonstrate that the proofs of Euclid's *Elements* were reducible to syllogistic form.²⁶ This is an area worthy of more scholarship, where a central question is whether these scholars themselves thought they were successful in demonstrating this syllogistic reduction. Whatever the answer, Ian Mueller has shown that not even the first proposition of the *Elements* is reducible to syllogistic form, the proposition depending ultimately on the relations between three straight lines and not on properties of them taken as pairs which a syllogistic analysis would require.²⁷

But there is a deeper ontological issue here of which the logical difficulties are only a symptom. It has to do with the underlying theory of ontic or 'material' predication. The Aristotelian model of material predication is *containment* — an attribute is 'present in,' 'inheres in,' 'is immanent in' its subject. The model is one of part to subsuming whole. This model of necessity restricts all predication ultimately to single subjects, i.e., all predicates are monadic predicates — properties. The related inference engine is, of course, syllogistic logic. Leibniz was perhaps the most consistent philosopher in explicitly enforcing the containment model in his doctrine of *praedicatum inest subjecto*. The simultaneous multi-subject predi-

cation of relations must now be explained away. Recall Leibniz's assertion that we would not want "to posit an accident which would inhere simultaneously in two subjects — one which, so to speak, has one leg in one and another leg in the other."²⁸ Hence, we have the torturous and spurious attempts at reducing relations to properties of their subjects, a tack found repeatedly throughout Western philosophy up to the turn of this century, and even now sporadically.²⁹ As it were, the monadic tail is wagging the polyadic dog. To borrow from Peter Geach a characterization of a closely related issue, the containment model of predication was, and in some quarters residually continues to be, a disaster for philosophy comparable to the Fall of Adam.³⁰ For in that model, relations lose any ontological, and hence any explanatory standing; they become, as Aristotle stated, "least of all real."³¹ Under this conception of relations the Aristotelian tradition was right to give mathematics, which embodies an intrinsic relational logic, only a purely descriptive role of 'saving the appearances.' Though unintended, what Galileo and Descartes helped to initiate in regard to the foundations of modern science was the loosening of the grip of two erroneous models — demonstratively certain *axiomatic* mathematics as a model for the form and character of scientifically established truths, and at a deeper level, the containment model of predication that robbed structural explanations of ontological legitimacy.

In sum, Aristotelian scientific methodology as well as its underlying ontology were incapable of providing structural explanations, but a 'Pythagorean' methodology incorporating applied mathematics could. And though structural explanation is inherently hypothetical, it was its relative power and its facility as a 'logic of discovery' that impressed Galileo and Descartes and provided the success that eventually dislodged the grip of the Aristotelian theory of nature.

²⁴Quoted in Drake, *Galileo at Work*, 199.

²⁵On the irreducibility of polyadic relations to monadic properties and a history of such attempted reductions, see my *Moderate Realism and Its Logic* (New Haven: Yale University Press, 1996).

²⁶References for these attempted reductions of proofs in Euclid's *Elements* to syllogistic form are found in Neal Gilbert, *Renaissance Concepts of Method* (New York: Columbia University Press, 1960), 89–90.

²⁷Ian Mueller, "Greek Mathematics and Greek Logic," in *Ancient Logic and Its Modern Interpretations*, ed. John Corcoran (Dordrecht:

Reidel, 1974), 35–70.

²⁸Gottfried W. Leibniz, *Philosophical Papers and Letters*, 2nd. ed., ed. Leroy Loemker (Dordrecht: Reidel, 1969), 704.

²⁹For example, Keith Campbell in his *Abstract Particulars* (Oxford: Basil Blackwell, 1990) presses for a monadic reduction of relations. See my *Moderate Realism*, 164ff., for a rebuttal.

³⁰Peter Geach, *Logic Matters* (Berkeley: University of California Press, 1980), 47 and 290.

³¹Aristotle, *Metaphysics* 1088a20.