Book Review

La Rivoluzione Dimenticata (The Forgotten Revolution)

Reviewed by Sandro Graffi

La Rivoluzione Dimenticata
(The Forgotten Revolution)
Lucio Russo
Feltrinelli, Milan, 1996
380 pages
Hardcover $30.00

The conquests of Alexander the Great superimposed the Greek culture over the older Middle Eastern ones of Egypt, Mesopotamia, and Persia. The consequent cross-fertilization was epoch-making and gave rise to Hellenistic civilization. Its main center was Alexandria, with its Museum and its Library, in many aspects comparable to the present-day advanced research institutes.

In *The Forgotten Revolution* the author, a probabilist at the University of Rome II and a professional classical philologist as well, sets out to reconstruct Hellenistic science between the foundation of Alexandria in 331 B.C. and the first closure of the Museum in 145 B.C., the golden age of science in antiquity.[1]

The book is a comprehensive and in-depth review of Hellenistic science. Its first conclusion represents an innovation, even with respect to classics such as Otto Neugebauer's *Exact Sciences in the Antiquity* or Sir Thomas Heath's *A History of Greek Mathematics*: the Hellenistic scientists were no simple "forerunners" or "anticipators" of modern science and technology, able maybe to go far on particular issues through sophisticated arguments but basically amateurish, unlike the present-day professionally trained scientists and technologists. On the contrary, they were real pros: the Hellenistic civilization was largely based on a scientific revolution amounting to the introduction of today's scientific method and scientific technology, including much of today's mathematics, *in today's formulation* (Euclidean geometry, real numbers, limits, definite integrals) and of solid and fluid mechanics (whence civil, mechanical, naval engineering), optics, astronomy, anatomy, physiology, scientific medicine, even psychoanalysis.

The second conclusion goes even further: in the same way that the Renaissance was based on the recovery of classical culture,[2] the post-Renaissance scientific revolution of the seventeenth century was basically due to the conscious recovery of the Hellenistic science (not even to its full extent, reached only in the second half of the nineteenth century with Dedekind's and Weierstrass's isolation of the real number concept directly out of Euclid's definition of proportion). Unlike artists and humanists, however, the scientists (e.g., New-

Sandro Graffi is professor of mathematical physics at the University of Bologna. His e-mail address is graffi@dm.unibo.it.

[1] *Those active in Alexandria include the mathematicians and physicists Euclid and Heratosthenes, the physician Herophilos, and many others; elsewhere, the mathematician, physicist, and engineer Archimedes of Syracuse, the mathematician Apollonius of Perge, the astronomers Aristarchus of Samos and Hipparchus of Nicea, etc.*

[2] *Including Euclid's* Elements *and* Optics, *the basis of Hellenistic perspective rediscovered in the early fifteenth century. The annotated Latin translation of the* Elements *belonging to Leon Battista Alberti (1401-1478), one of the first and foremost Renaissance architects and painters, still exists in Florence (Biblioteca Laurenziana).*

ton) and their popularizers (e.g., Voltaire), being probably more insecure in their achievements and thus more anxious to take credit, did not pay the debt due to their true sources.

The novelty of these conclusions is such that one might be tempted to react with plain disbelief, if not with a shrug. The reader should, however, avoid such a reaction, because the scholarly support is unquestionably impressive. It includes a methodological novelty, this time in the examination of the original sources. Thanks to his dual competence in science and philology, Russo does away with a time-honored habit among scholars of antiquity—namely, that humanists only deal with "literary" sources and historians of science with the "scientific" ones. The scarcity of the extant sources on science in antiquity forces the modern scholar to look for all second- or third-hand information scattered and interspersed through the literary ones. The examination of many more sources than the traditional ones not only adds to the historical perspective but yields new findings in the history of science. One of the two most interesting, in my opinion—the discovery of the inverse square law of gravitation in Hellenistic times (the other being the philological deduction that Euclid's definitions are not in the original text)—comes mainly from reading historians or philosophers such as Plutarch or Seneca with the eye of a scientist.

The second conclusion is even more daring. Here again, however, the examination of the original literature (Galileo, Kepler, Descartes, and especially Newton) and of the related matters of historical relevance,[3] particularly in relation to the Hellenistic sources, is so careful that, to say the least, it cannot be easily dismissed.

The topic is covered in ten chapters, an epilogue, and a mathematical appendix. Chapters 1–7 cover in detail the birth, rise, decline, and fall of Hellenistic science and technology: mathematics, mechanics of solids and fluids, topography and geodesy, optics, astronomy; civil, mechanical, naval, and military engineering; anatomy, physiology, biology, and medicine; economics and mass production techniques; architecture and urban development; psychoanalysis and cognitive sciences. In Chapter 1 the isolation of today's concept of "exact science", both theoretical and experimental, is reconstructed, comparing the quantum jump between the arguments on mechanical advantage of gears of Aristoteles (d. 331 B.C.), negating their feasibility, and Archimedes (d. 212 B.C.), first asserting the contrary theoretically and later supervising their construction.

From Chapter 2 on Hellenistic mathematics I give an example of a recurrent argument in the book: to assess Hellenistic science, and especially its modern aspects, commonplace opinions should be reevaluated. One of these states: in Greek science the concept of infinity is poorly understood and openly avoided.[4] The view of the Hellenistic mathematicians is instead much the same as that, for instance, of G. H. Hardy[5]: "There is no number infinity: such an equation as $n = \infty$ is as it stands *meaningless*. A number n cannot be equal to ∞ because 'equal to ∞' means nothing." To prove his case, the author simply reproduces in full Archimedes' famous computation of the area of the parabolic segment by the exhaustion method. Archimedes, it is true, does not use the word "limit". If this word is, however, replaced by its present-day definition, his statement is exactly reproduced, and, again, replacing a word by its definition results in a Riemann integral. Actually, the author's main point about Hellenistic mathematics is its methodological nature: even more important than what Euclid, Archimedes, and Heratosthenes actually discovered is the method they introduced, namely, the axiomatic, deductive way of argumentation which characterizes mathematics. More generally, the deductive approach, coupled to the experimental method also introduced by the Hellenistic scientists, is our own approach to exact sciences. The Hellenistic scientific revolution was forgotten precisely because that scientific method was abandoned in antiquity and its recovery was exceedingly slow. For example, coming back to mathematics, Newton was still far below the Hellenistic level of rigor, as evident from comparing his argument about the ratio of infinitesimal quantities (*Principia*, I.I) with Archimedes' work *On Spirals*, where infinitesimals of different orders are introduced: in essence, Newton lacked the limit concept which Archimedes possessed. The full recovery of the Hellenistic way of doing mathematics had to wait for Cauchy and Weierstrass.

The two subsequent chapters deal mainly with optics, mechanics and astronomy, and engineering. Their purpose is to show how the main achievements of Hellenistic technology, whose memory is still alive today (the Colossus of Rhodes; the lighthouse of Alexandria, whose rays could be seen from a distance of more than thirty miles; Archimedes' machines; ships with metal-protected hulls and up to thirty orders of rows, etc.) were made possible by the sound scientific ground on which the engineering was based.

The same scientific method characterizes the investigations in biomedical sciences (here the main

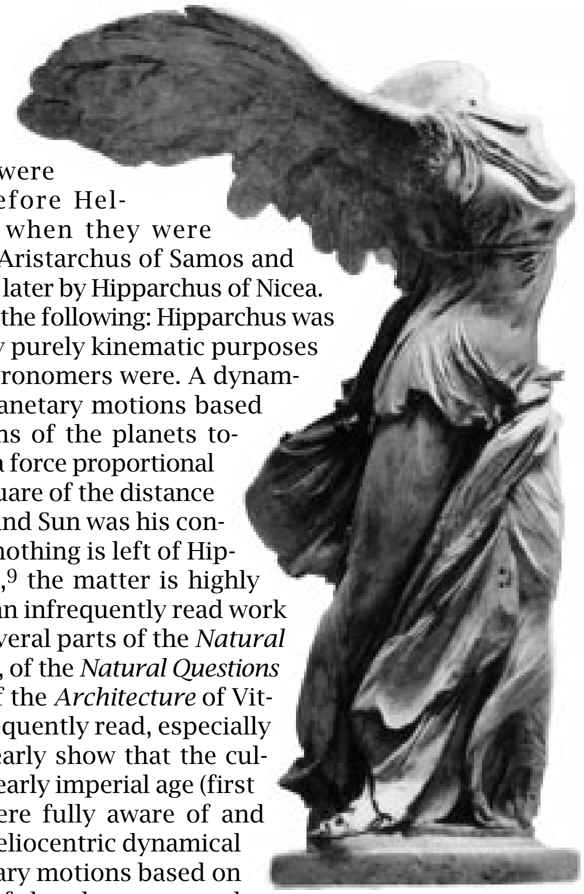
[3]*For example,* Scholia, *related to the various writing stages of* Philisophiae Naturalis Principia Mathematica*; list of books in Newton's library; etc.*

[4]*See, e.g., M. Kline,* Mathematics in Western Culture*, Oxford, 1953, or C. Boyer,* A History of Mathematics*, New York, 1968.*

[5]A Course of Pure Mathematics*, Cambridge, 1963, §55.*

figure is Herophilus of Chalcedon,[6] who developed a theory, very much like our modern ones, of human anatomy and physiology, discovered the nervous system, and made a distinction between sensors and motors), in economics and mass production techniques, in architecture and urban development, and in cognitive sciences. Taken as a whole, the scientific methods characterized Hellenistic civilization, which underwent a major crisis in 145–144 B.C. (under Roman pressure after the subjugation of Macedonia and the destruction of Carthage) and later a slow but steady decline during its forced integration into the Roman state, concluded in 30 B.C. with the reduction of Egypt to a Roman province. However, Alexandria maintained its role as the scientific capital of antiquity (with a partial recovery in the second century A.D., the time of the mathematician and mechanical engineer Heron, the physician Galenus, and the astronomer Claude Ptolemy) well into the fifth century A.D. To fix the time scale, note that the rise, decline, partial recovery, and fall of Alexandrine science took more than seven centuries.

Before turning to the question of the decline of Hellenistic science, I come back to the new light shed by the book on Euclid's *Elements* and on pre-Ptolemaic astronomy. Euclid's definitions of the elementary geometric entities—point, straight line, plane—at the beginning of the *Elements* have long presented a problem.[7] Their nature is in sharp contrast with the approach taken in the rest of the book, and continued by mathematicians ever since, of refraining from defining the fundamental entities explicitly but limiting themselves to postulating the properties which they enjoy. Why should Euclid be so hopelessly obscure right at the beginning and so smooth just after? The answer is: the definitions are not Euclid's. Toward the beginning of the second century A.D. Heron of Alexandria found it convenient to introduce definitions of the elementary objects (a sign of decadence!) in his commentary on Euclid's *Elements*, which had been written at least 400 years before. All manuscripts of the *Elements* copied ever since included Heron's definitions without mention, whence their attribution to Euclid himself. The philological evidence leading to this conclusion is quite convincing.[8]



Heliocentric theories of planetary motions were known long before Hellenistic times, when they were reelaborated by Aristarchus of Samos and then one century later by Hipparchus of Nicea. The point here is the following: Hipparchus was not motivated by purely kinematic purposes as the earlier astronomers were. A dynamical theory of planetary motions based on the attractions of the planets toward the Sun by a force proportional to the inverse square of the distance between planet and Sun was his contribution. Since nothing is left of Hipparchus's works,[9] the matter is highly debatable. Now an infrequently read work of Plutarch,[10] several parts of the *Natural History* of Plinius, of the *Natural Questions* of Seneca, and of the *Architecture* of Vitruvius, also infrequently read, especially by scientists, clearly show that the cultural elite of the early imperial age (first century A.D.) were fully aware of and convinced of a heliocentric dynamical theory of planetary motions based on the attractions of the planets toward the Sun by a force proportional to the inverse square of the distance between planet and Sun. The inverse square dependence on the distance comes from the assumption that the attraction is propagated along rays emanating from the surfaces of the bodies. The difficulties experienced by those authors in reproducing technical arguments which they did not fully grasp indicate, even more than their indirect references to earlier "learned men", that they were writing on the basis of earlier sources. An accurate examination of all the extant related literature strongly supports the opinion that the true source must have been Hipparchus.[11]

How much of the above was known to Newton? We learn that Definition 5 (centripetal force) of the

[6]*Active in Alexandria in the beginning of the third century B.C. On this point the author acknowledges his debt to H. von Staden,* Herophilus. The Art of Medicine in Early Alexandria, *Cambridge, 1989.*

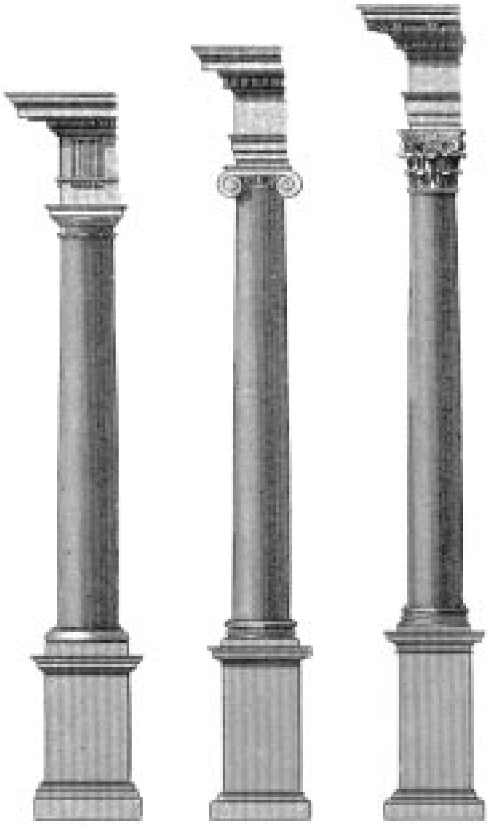
[7]*"The language thus seen is hopelessly obscure" is the comment of T. L. Heath,* op.cit.*, after the definition of straight line.*

[8]*The book reproduces the original argument of L. Russo,* "On the non-authenticity of the definitions of the fundamental geometric entities in Euclid's *Elements*", *Bolletino dei Classici, Accademia Nazionale dei Lincei (Rome) XIII, 1992, pp. 25-44. An enlarged English version of the argument is in press: L. Russo,* The definition of fundamental geometric entities contained in Book I of Euclid's *Elements, to appear in* Archive for History of Exact Sciences.

[9]*The most important of them were lost after only 300 years. Claude Ptolemy had the complete list of publications of Hipparchus, but not the main astronomical works themselves.*

[10]De facie quae in orbe lunae apparet *(On the light glowing on the Moon). The complete works of Plutarch were present in Newton's library.*

[11]*An English version of the argument can be found in: L. Russo,* The astronomy of Hipparchus and his time: a study on pre-Tolemaic sources*, Vistas in Astronomy* ***38*** *(1994), 207–248.*



Principia is almost the translation of Plutarch's rendering of the same concept. Likewise, the illustration (Comment after Definition 5) of centrifugal force through the example of the stone put in rotation through a sling is in Plutarch's *De facie*. Moreover, in the *Scholia*[12] of the *Principia* (published only in 1981!) Newton had inserted, without quotation, several chosen passages of *De facie*, including the full development of the abovementioned ones, in which Plutarch argues that the Moon keeps going along its circular orbit and does not fall on the Earth by compensation between centripetal attraction and centrifugal force. The passage of Seneca in which Plutarch's theory of the motion of the Moon around the Earth is applied to explain the planetary motions—the center being this time the Sun—also appears, again without quotation, in the fragments, as well as another passage about the motions of the comets in *De mundi systemate Liber I*. What about the inverse square law? Again in the *Scholia* Newton gives credit for its discovery to Pythagoras (while in the *De mundi systemate Liber I* he credits the second king of Rome, the legendary Numa Pompilius, for the introduction of heliocentrism, suggesting, however, that he may have had it from the Egyptians). Hooke thought of deducing Kepler's laws out of the inverse square law before Newton and communicated his idea in a letter[13] to him. We learn then that the inverse square law can be traced back, through Boulliau, Kepler, Roger Bacon, to the abovementioned *Architecture* of Vitruvius. The Hellenistic sources were thus forgotten by a kind of "double censorship" mechanism: first by Newton himself and second by his followers, who never published those of his works which could make clear his dependence on them.[14] Voltaire's invention of the tale of Newton's apple put the final seal to the matter.

[12]Scholia = *annotations on the original manuscript not appearing in the printed version.*

[13]*Whence the well-known controversy between the two.*

[14]*The* Scholia *related to the* Principia *were published only in 1981, and the* Treatise on Apocalypse *in 1994.*

Why then did Hellenistic science decline under the Roman empire and eventually disappear? Why, to begin with, did many Hellenistic works, even those among the most important, cease being copied well before Claude Ptolemy was writing the *Almagest* around 150 A.D.? Why did the selection process work in reverse, saving some of the worst and throwing away much of the best? This question is considered in Chapter 8. An example illustrates the author's argument. Imagine a slow but steady impoverishment of the deductive and quantitative contents of scientific culture, so that in time mathematics courses are no longer offered in colleges. Imagine also such a shortage of space that just a small fraction of the printed books can be conserved. Now take orbit theory and spacecraft navigation, namely, dynamical systems and celestial mechanics. What books would be selected after, say, 200 years? Poincaré's *Méthodes Nouvelles* and Siegel-Moser's *Lectures on Celestial Mechanics*, or just some descriptive book of today, richly illustrated with color pictures of fractals and coming with some (usually already outdated) software for computing orbits?

What about the general and steady (on the average) impoverishment of Hellenistic science under the Roman empire? This is a major historical problem, strongly tied to the even bigger one of the decline and fall of the antique civilization itself. I would summarize the author's argument by saying that it basically represents an application to science of a widely accepted general theory on decadence of antique civilization going back to Max Weber. Roman society, mainly based on slave labor, underwent an ultimately unrecoverable crisis as the traditional sources of that labor force, essentially wars, progressively dried up. To save basic farming, the remaining slaves were promoted to be serfs, and poor free peasants reduced to serfdom, but this made trade disappear. A society in which production is almost entirely based on serfdom and with no trade clearly has very little need of culture, including science and technology. As Max Weber pointed out, when trade vanished, so did the marble splendor of the ancient towns, as well as the spiritual assets that went with it: art, literature, science, and sophisticated commercial laws. The recovery of Hellenistic science then had to wait until the disappearance of serfdom at the end of the Middle Ages. To quote Max Weber: "Only then with renewed vigor did the old giant rise up again."

This book shows how complex and unstable the preservation of science is when the unit of time of historical observation is the millennium. The epilogue contains the (rather pessimistic) views of the author on the future of science, threatened by the apparent triumph of today's vogue of irrationality even in leading institutions (e.g., an astrology professorship at the Sorbonne). He looks at today's ever-increasing tendency to teach science more on a fideistic than on a deductive or experimental basis as the first sign of a decline which could be analogous to the post-Hellenistic one. I quote:

> As in the Roman empire age, the theoretical concepts, taken out of the theories assigning their meaning and considered instead real objects, whose existence can be apparent only to the initiated people, are used to amaze the public. In physics courses the student (now unaware of the experimental basis of heliocentrism or of atomic theory, accepted on the sole basis of the authority principle) gets addicted to a complex and mysterious mythology, with *orbitals* undergoing *hybridization*, elusive *quarks*, voracious and disquieting *black holes* and a creating *Big Bang*: objects introduced, all of them, in theories totally unknown to him and having no understandable relation with any phenomenon he may have access to.

If this concern is justified, then the present scientific revolution will in time be forgotten, and new Dark Ages are awaiting our descendants. In the words of Francis Bacon, quoted at the beginning of J. L. Borges' *The Immortal*:

> Solomon saith: there is no new thing upon the earth. So that as Plato had an imagination, that all knowledge was but remembrance; so Solomon giveth his sentence, that all novelty is but oblivion.