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Justification, Creativity, and Discoverability in Science

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On scientific creativity and its limitations

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> Between the idea and the realization of the intention always lies a period of work and effort typical of the inventive process. [...] The arising of the idea is that happy moment in the creative activity of thought in which everything seems possible, since it has nothing to do with reality yet. Execution is the moment when one has to procure all the means necessary for the realization of the idea, a moment still creative, still happy, a moment when one has to overcome the resistances of nature; from it one always emerges tempered and ennobled, even if beaten.
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> Rudolf Diesel, *Die Entstehung des Dieselmotors*, Berlin 1913, pp. 151–152

1 Modern science was born in the seventeenth century

Science was born in the seventeenth century, the age of the Baroque. Is this an accident? I do not think so. In many historical reconstructions, especially those devoted to Italian history, there is an insistence that the seventeenth century constituted an age of crisis. If it was a time of "crisis", however, it was a very strange "crisis". For what reason? Because with the birth of modern science a genuine point of no return was introduced into the history of all mankind. Not for nothing did an English historian such as Herbert Butterfield in his *The Origins of Modern Science* (1958) argue that the birth of science constituted a genuine turning point:

> Since that revolution overturned the authority in science not only of the middle ages but of the ancient world—since it ended not only in the eclipse of scholastic philosophy but also in the demolition of Aristotelian physics—it outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the level of mere episodes, mere internal displacements within the system of medieval Christendom. Since it changed the character of men's habitual mental operations even in the conduct of the non-material sciences, while transforming the whole diagram of the physical universe and the very texture of human life itself, it looms so large as the true source of the modern world and of the modern mentality that our customary periodisation of European history has become an anachronism and an encumbrance.[1]

This approach was largely shared by an Italian epistemologist such as Ludovico Geymonat, who in his monumental *History of Philosophical and*

[1] H. Butterfield, *The Origins of Modern Science*, G. Bell & Sons Ltd, London 1958, pp. VII–VIII.

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F. Minazzi, On scientific creativity and its limitations, pp. 141–148.

Scientific Thought (in 7 vols.) precisely assumed the birth of modern science as the authentic and fundamental turning point in human history. So much so that by leveraging this strategic "Archimedean" point, Geymonat overturned the traditional historiographical framework of the main *Histories of Thought*, devoting 5 volumes of his great *History* to the study of modernity and the contemporary era. Geymonat also always considered scientific thought, entwined with philosophical thought, as the privileged *fil rouge* of his historical reconstruction. Thus, as his *History* approaches the present era, the volumes expand and deepen and are dilated, to the point where two very large volumes are devoted to twentieth-century thought, flanked by another tome for the study of the transition between the nineteenth and twentieth centuries. In contrast, only one volume, the first, is devoted to ancient and medieval thought. This critical reversal of the traditional historiographical approach (which, in general, pays increasing attention to the centuries of the distant past, gradually reducing its focus on the contemporary age) rests on the conviction that, since science first developed in the seventeenth century, nothing has been the same as before. In the words of Bertrand Russell in *The Scientific Outlook* (1931), "one hundred and fifty years of science have proved more explosive than five thousand years of prescientific culture".[2]

In this reconstructive context, the acknowledged father of modern science is, without a doubt, Galileo Galilei. He provided the first outline of modern science, working at the turn of the 16th and 17th centuries, although it was in the latter century that his most important and significant works appeared. Notably, his scientific masterpiece was published just when Galileo had already been condemned, following the famous inquisitorial trial to which he was subjected, since his *Discourses and Mathematical Demonstrations Relating to Two New Sciences* was published anonymously in Leyden by Elzevier in 1638. If Galileo had not published this scientific treatise, he would not be considered the acknowledged father of modern science. If anything, he would have been remembered as a scholar who contributed, in a very significant and timely way to defending the Copernican theory, favouring its affirmation. In this key, Galileo would thus resemble Giordano Bruno as a courageous advocate of the new heliocentric and heliostatic astronomical theories. On the contrary, the very publication of the *Discourses* qualifies Galileo as the first scientist of modernity who made a decisive contribution to the birth and development of modern science. In fact, the two sciences discussed in the *Discourses* are, precisely, the resistance of materials and dynamics, the science of motion, i.e., that of a rigid body moving at a speed significantly less than the speed of light.

[2]Bertrand Russell, *The Scientific Outlook*, George Allen & Unwin, London 1931, p. 9–10.

2 Baroque science and culture: imagination and sense of reality

According to Fernand Braudel,[3] Baroque culture constituted a new form of taste, culture and even 'civilisation' that spread from Italy to the whole of Europe, helping to create modern theatre, opera and modern science. But how can the specific contribution of Baroque culture be specified? I would say that Baroque culture insisted on two different and yet interrelated moments, namely the sense of reality and the role of imagination. Thus, on the one hand, there is a kind of profound reaction to the traditional balance of classical rationality, which was now intertwined with an eccentric, bizarre, paradox-loving creativity, but, on the other hand, precisely within this same unbridled imagination, the almost infinite complication of reality is also recovered. Precisely because—in the words of an eminent writer like Carlo Emilio Gadda—the world is very complex and always entangled, precisely because it resembles a . . . dumpling.

Well, precisely this unique intertwining of imagination and sense of reality is also found within the Galilean image of science. This statement may seem provocative, since we are often conditioned—willingly or unwillingly—by an empiricist image of science, according to which scientific knowledge is, in the final analysis, a derivative and a product of sense and experimental experience itself. This traditional image of science has also largely dominated epistemological thought, so much so that the tradition of empiricism—from Hume's to the Viennese brand of logical empiricism—has provided a privileged frame of reference for trying to construct a correct image of scientific knowledge. However, it is precisely the historical and conceptual hegemony of this albeit fruitful epistemological research program, based on empiricism, that has contributed to the diversion from a correct image of scientific knowledge. The latter does not derive so much from experimental experience by inductive means, for it arises, if anything, from a complex interplay that is more highly articulated and also much more fruitful.

If one considers the various reactions aroused in Galileo's contemporaries by the reading of his *Discourses*, it is easy to understand this problem concerning both the genesis of modern science and its epistemological structure. When Aristotelian physicists read Galileo's *Discourses* and his innovative treatment of the motion of rigid bodies, there was no shortage of direct reactions. Such as that of the Genoese physicist Giovanni Battista Baliani, the author of a book *De motu naturali gravium solidorum* (1638) in which this physicist had reached, by experimental means, the correct determination of the law that regulated falling bodies. For this reason, Baliani in his correspondence with Galileo insisted on emphasizing the decisive role of

[3]See F. Braudel, *Out of Italy: Two Centuries of World Domination and Demise, Europa Editions*, London 1994, pp. 66–67.

experience, which, in his opinion, also derived from almost all of Galileo's work, in deep harmony also with Aristotle's teaching, aimed at putting experience before our theories, as Galileo himself repeatedly emphasized in his *Dialogue Concerning the Two Chief World Systems* (1632). In fact, Baliani (in a letter dated 1 July 1939) wrote: "I in truth have judged that experiences should be taken as principles of science, when they are certain, and that from things known by sense it is part of science to lead us into cognition of the unknown" (XVIII, 69).[4]

Before this privileged appeal to the foundational role of experience, Galileo, in his earlier letter of 7 January 1639, had, however, already written to Baliani (thanking him for sending him his book on motion) noting that he had

> himself dealt with that subject [of motion—*ed.*], but in a much more extensive way and with a different approach. This is due to the fact that I do not admit as a hypothesis anything except the definition of motion, which I wish to deal with by demonstrating its accidents, in this imitating Archimedes on Spirals. (XVIII, 11–12).

In other words, Galileo, while claiming that he also dealt with the problem of the motion of bodies, stresses that he nevertheless followed a different path. In fact, Galileo, unlike Baliani, did not start from the study of experience, but rather from some definitions that he introduced *ex suppositione*, that is as a hypothesis, merely conjecturally. In carrying out this "different attack" of his, Galileo declares, however, that he is referring back to the great scientific model of Archimedes of Syracuse, who, in *De Spiralibus*, also started from some hypothetical definitions, caring little whether or not these geometric forms existed in the world. For this reason Galileo also specifies the following:

> but returning to my treatise on motion, I argue *ex suppositione* regarding motion, defined in that way; so that even if the effects did not correspond to the accidents of the motion of descending weights (bodies), it would matter little to me, just as nothing is lacking in Archimedes' demonstrations due to the fact that no moving body (moveable) is found to move in spiral lines. But in this I was, so to speak, fortunate, because the motion of bodies and their accidents correspond exactly to the accidents demonstrated by me relating to motion as I have defined it. (XVIII, 13).

In this way Galileo explains how, in order to construct his innovative theory of motion, he essentially proceeded in this way: first, he introduced

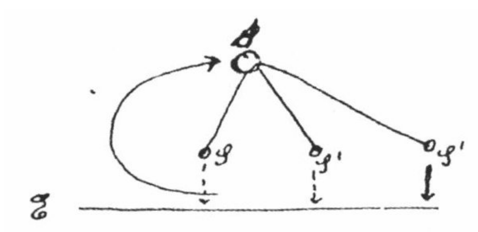
[4]This and all the other quotations from Galileo's writings that follow in the text are taken from the Edizione Nazionale of *Le opere di Galileo Galilei*, edited and directed by Antonio Favaro, G. Barbèra Editore, Florence 1968, 20 vols., The volume is shown in Roman numbers and the reference page in Arabic numbers. The translations are mine.

hypothetical, arbitrary definitions, which we might describe as absolutely conventional, precisely *ex suppositione*. Taking these conjectural definitions as a starting point, a theory is then constructed—by rigorously *deductive* means—which implies certain *consequences* and specific *predictions*. Finally, as the third constituent moment in this way of proceeding, it is precisely these consequences—that is, the "predictive" component of the theory—that are placed in close comparison with the *experimental dimension* in order to be able to confirm, or falsify, these same predictions. In this way, the articulated Galilean picture of scientific knowledge is not empiricist at all, but deductive and normative, because at its core it contains different moments that are interwoven with each other in an absolutely innovative way. With the consequence that the *physical object* is not then derived directly from experience, but is instead constructed and elaborated, in the first instance, by the imagination of the scientist, who on this very basis subsequently builds, by *deductive* means, a theory, the predictive *consequences* of which are finally checked and rigorously verified within the experimental dimension. Thus in the Galilean model of science there subsist different and opposing elements: that of the creative and conventional imagination, that of rigorous logical-mathematical deduction and, last but not least, the moment of verification—or experimental falsification. It is all of these different "moments" that, taken together, finally configure a scientific theory worthy of the name because it is capable—in the words of Leonardo da Vinci—of enabling us to grasp "a thread of truth". Therefore, even in the Galilean heuristic model, the experimental dimension undoubtedly plays a fundamental and decisive role, but it does not constitute the primary horizon from which one starts to construct a theory, because it has the equally fundamental and crucial role of being able to subject the theory that has been devised to a critical-experimental check. The experimental dimension thus plays a part that is not located at the beginning of the process (as Baliani argued in his treatise and letter of July 1639), because it plays, instead, its part precisely in the concluding and decisive phase of scientific reflection, that is, the one devoted to the rigorous experimental control of the different theoretical predictions.

The epistemological model thus outlined by Galileo is a decidedly counterfactual model. This confirms that for Galileo the image of knowledge is constructed by interweaving the imaginative capacity of the scientist with his vivid sense of experimentally investigated reality in order to be able to place theoretical predictions under critical scrutiny. This is why Galileo proudly claims to have followed an "aggressione diversa" (a "different approach"), wishing to clearly distinguish himself from Baliani's empiricism, which instead emphasises precisely the constructive role of valuing experience as the authentic foundation of knowledge. Within the plane of the history of epistemological thought, it is undoubtedly the case that it was precisely Baliani's inductivist and empiricist image that was very widely successful, while the Galilean one was gradually forgotten and removed. Which constitutes a curious fate, which can, however, be easily explained if one keeps in mind that empiricism has been, over the centuries, a highly privileged point of reference, especially for English-speaking culture and its various admirers. In this sense, the empiricist image of science has thus dominated unchallenged from the seventeenth century until the contemporary age. Of course, this is by no means to deny a definite role and function of the experimental dimension within the construction of scientific knowledge. But, precisely in light of the timely Galilean considerations, it is, if anything, a matter of knowing how to construct a more correct and articulated and truthful image of the specific ways in which scientific knowledge grows and is constructed in the praxis of scientific research.

3 Einstein and his conception of science

In the early 1950s, Albert Einstein was urged by his friend Maurice Solovine to illustrate his overall conception of scientific knowledge. In response to this question from a lifelong friend, Einstein, in his letter of 7 May 1952, submitted the following drawing:[5]



In this drawing, Einstein explains, the *E* line indicates the set of immediate experiences. That is, what we might refer to, with Husserl, as the *Lebenswelt*, the world of life, in which we all live as ordinary men and women because in this pragmatic dimension we are all present and active through the praxis we enact (and also undergo). This horizon common to all of us is, indeed, precisely the "world of life", which everyone—the scientist, the common man in the street, as well as the Nobel laureate—shares and within which they live and exercise their action as persons "of flesh and blood".

Point *A*, on the other hand, indicates axioms from which conclusions can be deductively drawn. In Einstein's drawing, the line leading to *A* is

[5]See A. Einstein, *Lettres a Maurice Solovine*, Gauthier-Villars, Paris 1956 and the English-language edition, A. Einstein, *Letters to Solovine*, The Philosophical Library, London 1994, where the letter quoted is on pp. 124–125.

represented by the arc of a parabola that appears slightly detached from line E. This "detachment" is precisely meant to emphasise the relative independence of the human imagination, which, while floating above the world of sensible perceptions, nevertheless manages to develop its own independent and autonomous path by which it comes to postulate axiom A. There is therefore, notes Einstein, no logical path leading from E to A. There is at most an intuitive connection that nevertheless enjoys its own relative autonomy within which the human imagination exercises its function.

It also emerges from the drawing that from the A's one can derive, this time by a rigorously deductive procedure, some particular utterances S that constitute the consequences of the theory and aspire to be true. But the verification—or falsification—of these utterances S occurs solely through comparison mediated by technology, which allows for the establishment of a decidedly experimental framework. However, Einstein points out, "this relation between the S's and the E's is nevertheless (pragmatically) much less uncertain than that which exists between the A's and E's (e.g., between the concept of dog and the corresponding immediate expressions). If such a correspondence, while remaining inaccessible to logic, could not be established with a high degree of certainty, the whole logical apparatus would be of no value for the purpose of 'understanding reality', e.g., theology)."

On the other hand, in the drawing, what joins the S's to the line E is indicated with a hatching that is intended precisely to emphasize the problematic character of this link that is established between theories and reality. Einstein writes: "The essential aspect here is the eternally problematic link between the world of ideas and what can be experienced (sensible experience)." Exactly in this problematic nexus between the theoretical plane of ideas and thoughts and its direct connection with the actual, real world lies that plane of scientific activity within which Galileo said that the scientist must be able to "climb over the impediments of matter". For this reason, as Rudolf Diesel also acknowledged in the quotation placed as an epigraph at the opening of this paper, "every inventor must be an optimist: the power of the idea retains all its active force only in the soul of its author, and only this one possesses the sacred fire of its realisation."[6]

In any case, all these elements—precisely represented by the E line, the A's, the S statements and the problematic link with the world of sense praxis mediated by the technological-experimental connection—configure the Einsteinian image of science. It is not difficult, however, to discern the profound similarity and close congruence that exists between this Einsteinian image of science and Galileo's illustrated in the previous section. Both of these two eminent physicists thus developed a complex and articulated image of scientific knowledge within which various elements—even decidedly

[6]Rudolf Diesel, *Die Entstehung des Dieselmotors*, Berlin 1913, p. 152.

contrasting—nevertheless play their own precise heuristic part to enable us, finally, to elaborate an objective knowledge of reality. Naturally this objective knowledge of reality can only be intrinsically problematic because, as mentioned earlier, it merely allows us to grasp a "thread of truth." In other words, this epistemological conception of scientific knowledge is never an absolute achievement, but always relative and critically appropriable. On the other hand, this outcome does not open up to any relativism precisely because we are in the presence of objective knowledge, which is always constructed within a well-defined and known context. For this reason, this objective knowledge, circumscribed to a finite and determinate physical sphere, is, within the limits of this finite configuration, also an "absolute" knowledge, that is, a knowledge that, within those determinate limits, allows us precisely to distinguish knowledge from lack of knowledge. We are thus in the presence of a historical-objective knowledge that by its nature always constitutes a historical-evolutionary knowledge that can be constantly critically extended in order to identify a deeper level of knowledge. On the other hand, this historical-evolutionary epistemological model prevents us from speaking of an absolute truth capable of providing us with exhaustive knowledge of the real. On the contrary, the latter is always critically capable of being deepened, because the game of human knowledge develops precisely through the ability to constantly question the results achieved in order to extend, step by step, our own knowledge of this "strange world" into which we have been catapulted from birth.[7]

[7] For a fuller critical study from this epistemological perspective, the reader is referred to my recent volume *Historical Epistemology and European Philosophy of Science*, Springer, Cham 2022.