transversal
International Journal for the Historiography of Science

Transversal: International Journal for the Historiography of Science 2018 (5): 49-65
ISSN 2526-2270
www.historiographyofscience.org
Belo Horizonte – MG / Brazil

IDTC Dossier
Methods and Cognitive Modelling in the History and Philosophy of Science–&–Education

"Strange Trajectories": Naive Physics, Epistemology and History of Science

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Abstract:

In the 1980s *naive physics* almost suddenly became a field of research for physicists interested in teaching and experimental psychologists. Such research, however, was limited to accurately recording the bizarre Aristotelian responses of "layman" struggling with simple physics issues. Another research on this topic is that one of phenomenological origin: starting from the studies of the psychologist of perception Paolo Bozzi (since 1958) *naive physics* had entered the laboratory, and he was the first to find that the physical knowledges of the adult individuals were "Aristotelian". Bozzi took advantage of these results in order to hypothesize a substantial diversity and independence of the sensory system with respect to the cognitive-rational one. Other interesting perspectives were considered by Piaget, who in the 1980s, confirming the spontaneous Aristotelism of children, provided a still prolific epistemological direction of such investigations: finding an explanatory mechanism that projects on the level of science construction that one of individual cognitive development.

Keywords:

Naive Physics; Epistemology; History of Science; Psychology of Perception; Impetus

Received: 25 January 2018. Reviewed 10 September 2018. Accepted: 27 September 2018.
DOI: http://dx.doi.org/10.24117/2526-2270.2018.i5.06

The "Followers" of *Impetus*

Between the end of the 1970s and the early 1980s the interest in questions related to learning science in general and, more specifically, of mechanics were born – but perhaps it would be more appropriate to say they were "reborn", for reasons that we will see later. Surprisingly, what determined a lasting interest on this specific topic, was from the start the fact that by

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submitting simple questions of physics to a sample of individuals (different in number, age and training), the answers obtained had always a high percentage of errors and, moreover, these errors suggested a spontaneous adhesion to Aristotelian principles of mechanics, not Galilean or Newtonian. The first result (relating to the period mentioned above) obtained by research in cognitive psychology, showed very briefly what said above framing it as "Layman Physics" (Shanon 1976); but the studies that were most successful and which introduced a guideline for cognitive psychologists are undoubtedly those of McCloskey (McCloskey 1980; McCloskey, Caramazza and Green 1983; McCloskey, Washburn and Felch 1983; Kaiser, Proffitt and McCloskey 1985) and, among physicists, those ones of Andrea diSessa (diSessa 1982).

We consider, in particular, the most comprehensive one (McCloskey 1983), in preprint in 1980: McCloskey first of all stated that "Everyday life provides people with countless opportunities for observing and interacting with objects in motion" (McCloskey 1983, 299) and, therefore, his research aimed "at determining what sorts of knowledge in fact acquired through experience with moving objects" (McCloskey 1983, 299). The sample of forty-eight people subjected to non-quantitative problems on the behavior of moving objects belonged to three categories (all students at John Hopkins University in Baltimore): 1) students who had never attended a physics course (neither in college nor at high school); 2) students who had studied physics at the high school but not at the college; 3) students who had completed at least one physics course at the college. These people underwent a drawing in which a ball was released at a certain speed from the end of a hollow metal spiral tube; they were asked to draw the trajectory. "Somewhat surprisingly, a substantial proportion of subjects gave incorrect answers to the problems. For the spiral tube problem, 51% of the thought of the ball would follow a curved path after emerging from the tube" (McCloskey 1983, 302), instead, "the correct answer [...] is that after the ball leaves the tube it will move into the straight line in the direction of its instantaneous velocity at the moment it exits the tube [because] Newton's first law states that in the absence of a net applied force an object in motion will travel in a straight line" (McCloskey 1983, 301).

Another focal point of the investigation was to draw the trajectory of a metal ball dropped by an airplane at constant speed and altitude. The correct answer is that the ball will fall in a parabolic arc, since the horizontal component of gravity is zero, while the ball has got only a horizontal velocity as long as it is in the plane. "Nineteen subjects, or 40%, drew forward arcs that looked more or less parabolic [...]. Thirteen percent of the subjects thought that the ball would fall in a straight diagonal line, while another 11% mentioned that the ball would move backwards when released. However, the most common incorrect response, which was made by 36% of the subjects, was the ball would fall straight down" (McCloskey 1983, 303-4).[2]

Among the first relevant results, there is the one that "the same sorts of errors are made by the subjects in all three groups" (McCloskey 1983, 305) or those errors are distributed equally among the three categories of people examined, without significant differences between those who possessed notions of physics and who did not.

Before making some considerations about the "type" of error, which in our opinion are salient (i.e. epistemological and relative to history of scientific thought), we briefly recall another study, that one conducted by the physicist diSessa (later he became a teacher of "Education" at Berkeley) of MIT, in the first half of the 1980s, on a sample of elementary school students (diSessa 1982). He used a calculator (a computer) showing on its monitor the evolution of the motion of a "geometric turtle" (*Dynaturtle*) based on the application of variable force in the direction (diSessa 1982, 37-40). Apart from a more precise setting up of the experiment obtained thanks to the use of the computer instead of the paper-and-pencil

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[2] For the specific experiments results see McCloskey, Caramazza and Green 1980.

methodology and of the sample limited to a specific age group (children),[3] "one might characterize early stages of an Aristotelian theory of physics with a Newtonian reality" (diSessa 1982, 41).[4] Two different physics are used to solve the problem concerned: one attributed by the author to an abstract scheme (Newtonian), the other (Aristotelian) related to the Piagetian sense-motor scheme ("more like Piagetian action schemes", DiSessa 1982, 59); this reading of the results, not lacking of some suggestion, leaves an important question open: "Why do students come to dynaturtle with deep Aristotelian misconceptions?" (diSessa 1982, 63), that is, why Aristotle's mechanics emerges with arrogance in the explanations after more than 2000 years? Answering is not easy at all, especially for those who, like diSessa, were thinking of another problem: "The depth of our understanding of the student's knowledge state and our cleverness in engaging its subtleties may then determine the ultimate success or failure of our teaching efforts" (diSessa 1982, 64-5).

About what McCloskey, he, tenaciously, decided to carry out, on a sample of thirteen university students, a further research by the interview method in order to clarify the principles or the physical theories underlying the answers given above, i.e. he was looking for a *Naive Theory of Motion*, speedily found; in fact, "11 subjects held the same basic theory [...] which we will refer to as a naive impetus theory" (McCloskey 1983, 306), that is a medieval theory of clear Aristotelian inspiration "which draws a qualitative distinction between a state of rest (absence of impetus) and a state of motion (presence of impetus)" and therefore "is inconsistent with the principles of classical physics" (McCloskey 1983, 306).[5] The impetus, invented by Philoponus in the sixth century and revised by Buridan in the fourteenth century, is not a mould of the Aristotelian mechanics: in this one, just in order to emphasize one of the most important differences, movement is always caused by an external force applied, but this has been contradicted by Buridan. And the "modern students believe that objects are kept in motion by internal and not external forces. Thus, the students' naive conception of motion is most similar not to the Aristotelian theory, but the later impetus theory" (McCloskey 1983, 318).

McCloskey, like most of those interested in this subject during the same period, cannot and does not want to deepen the results of his research in a "speculative" direction; he does not go beyond a brief parallelism between medieval science and naive physics, functional to describing and completing his results. However, there is no need to criticize him because it is one of the first serious and thoroughly documented work on this matter; and one can still understand a certain "naively" behavioral drift when he recalled that "it may be useful [...] for physics instructors to discuss with their students their naive beliefs, carefully pointing out what is wrong with these beliefs, and how they differ from the view of classical physics", this to make students return to the ranks of the correct vision, in fact, "in this way, students may be induced to give up the impetus theory and accept the Newtonian perspective" (McCloskey 1983, 319).[6]

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[3] In fact, diSessa states: "We have not attempted to expand developmental links from the children's topics into the adults'" (diSessa 1982, 49). In order to indicate a substantial similarity of results with biggest subjects, diSessa leans on others' studies; see diSessa 1982, 56-7.

[4] At this moment I cannot carry out exhaustively the experiment, which conclusions I am interested in. For the necessary indications of what represents a Newtonian or Aristotelian motion in the specific context, see diSessa 1982, 41-2, 53-5.

[5] Of course, McCloskey explains in a more articulate way the incompatibility between the "Aristotelian" physics of *impetus* and Newtonian physics, even if, in this phase, he does not underline how the theory of *impetus* was born in the Middle Ages precisely in order to explain some issues of the Aristotelian physics. See McCloskey 1983, 306-11; Clagett 1961, 505-64.

[6] Also in Kaiser, Proffitt and McCloskey 1985 we find the idea that these errors derive "from the applications of an erroneous belief about natural motions" or from wrong perceptual experiences,

Reviewing quickly other researches gradually carried out, we remember Wandersee 1985, in whom we find very interesting and suggestive questions about the possible interdisciplinary dialogue between Didactics and History of Science, but without this disciplinary interaction going beyond a help that the second offers to "science educators" in order to guide students "along an instructional sequence that may aid development of a more reasonable understanding of the phenomena or principles" (Wandersee 1985, 581). Nancy Nersessian first supposes a structural connection between the history of science and intuitive explanations of motion. Merits and limitations of her research, in my opinion, lie all in the same choice: to find an "inferential structure that generates medieval explanations" (Nersessian and Resnick 1989, 412) and to suppose that there is an identical one underlying the intuitive explanations (see also Nersessian 1989). This basic idea, better articulated, was reiterated hoping for the birth of a "Cognitive History of Science", which however is vitiated, according to me, by the substantially reductionist way of considering cognitive science and by the consequent use of history in an ancillary mode (see Nersessian 1995).

In 1991 Colin Gauld showed that he had understood the parallelism between the ideas of students struggling with physics problems and some important advances in the history of science (see Gauld 1991); even if the question dealt with the common cognitive mechanisms, it was unfinished with regard to the hypotheses useful for designing new didactic paths. Donley and Ashcraft, on the other hand, were responsible for verifying the correctness and improving the methodology used in other researches (for example those of McCloskey) without essentially reaching different results (see Donley and Ashcraft 1992).

The long article by Stella Vosniadou and William Brewer (Vosniadou and Brewer 1992) shows an extension of previous research (McCloskey) into domain of observational astronomy in which we find models and theories about the shape of the Earth decidedly outdated. The sufficiently large sample of children, the accuracy in designing and conducting the experiments, the detailed presentation offered, the wide bibliography taken into account, do not show, however, stimulating considerations; on the epistemological level, they do not go beyond the attribution of the difficulties encountered by the subjects to a form of naive physics: "These [wrong] presuppositions appear to be a part of a more general theory of naive physics which filters children's interpretations of the physical world and constrains their mental models of the Earth" (Vosniadou and Brewer 1992, 578).

In 2004, a contribution by Bertamini, Spooner and Hecht was published confirming the results already known with rigorously conducted new experiences (this time in optics). The authors admit, once and for all, that "furthemore, physical expertise does not always improve naive understanding" (Bertamini, Spooner and Hecht 2004, 29), but they are not interested in epistemological problems and even less in interdisciplinarity: their aim is to highlight the strictly scientific implications of these errors in the visual field and in the interpretation of raw data. The research by Bianchi and Savardi recovers the previous results and, after a quick look at the debate on the origins of naive physical notions (seen significantly as "errors"), supposes that they "are in any case shaped by what the people see" (Bianchi and Savardi 2014, 10), or they are ultimately imputable to perceptual inaccuracies.

If perception scholars are relatively neutral in the face of the data and do not go too far in designing epistemological scenarios, cognitive psychologists try to deepen the question by solving it in ways that are affected in various means by the classic cognitive paradigm, reductionist in suggesting the origin of errors in the deepest recesses of our mind.

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and that they represent "cognitive limitations [that] may constrain the subject's ability to integrate all relevant factors in the problem" (Kaiser, Proffitt and McCloskey 1985, 539).

This is the case of a relatively recent research in which emphasis is placed on the idea that naive physics is a kind of wrong representation with respect to reality, due not to bad perceptions but rather to a superficial way of operating of our mind in certain circumstances, in fact: "It is combination of extrapolation based on experience, followed by induction of some heuristic to explain why a particular answer has been given, that we believe has led to the notion of a naive physics" (McLaren I., Wood and R. McLaren 2013, 1013), so naive physics would be just "an attempt to make sense" following the presentation of certain scenarios.

A different case is, in my opinion, the article by Smith and Casati of 1994. In it the issues of naive physics are faced from a philosophical and psychological perspective, with the very interesting result of highlighting the "unappreciated link between early Gestalt psychology on the one hand and contemporary developments in philosophy and in artificial intelligence research on the other" (Smith and Casati 1994, 227). Starting from Mach and Avenarius, passing through the Gestaltists Köhler, Lipmann and Bogen, the scholar of perception Gibson, the Italian psychologists of phenomenological-gestaltist derivation Benussi and Bozzi, the authors outline a series of research fields of the naive physics, still object of reflections and research (especially Artificial Intelligence, Ontology).

However, we should not omit that the perspective carried on by Smith and Casati is of analytic origin (that is, of analytic philosophy) and this often results into a generic schematicity in which we perceive the lack of argumentation and of narration in the face of issues consciously considered very important. However, it is not the case to blame anyone, especially those who, like Smith and Casati, had the merit of connecting research traditions that are very different and almost always unrelated to each other; no one before them, for example, had taken seriously into consideration psychologists like Kanizsa and Bozzi "demonstrating the existence of a *sui generis* organization of the perceptual world" (Smith 1995, 290).

Naive Physics

We think it is interesting to reflect on the research of Paolo Bozzi for several reasons that gradually will come to light. In the meantime, we recognize that if there is a misunderstood father of naive physics, this is just Bozzi: since 1958-59, 18 years earlier than Shanon's article (see Shanon 1976), he had found in the laboratory the presence of Aristotelians notions in the reading made by the individuals of the pendular motion and the one on inclined planes (Bozzi 1993, 29-67). Then, when for some years the subject had become fashionable (in the early 1980s),

> a letter arrived from Baltimore, written by Professor Caramazza, McCloskey's collaborator [...]. His letter was very friendly and polite; he had heard that in the past I had dedicated myself to problems that had to do with the persistence of Aristotle in the raw physical conceptions of people; and he asked me for the publications that I might have written on the subject. This letter made me very proud; I photocopied my old works [...] and sent a registered package to Baltimore with everything inside. I never received an answer, nor an acknowledgment, as they say. The parcel, surely, arrived in Baltimore, but it "dissolved" in a very deep silence, and I had no more news of Professor Caramazza, nor I saw his works in that area of research. Mysteries of the academic world (Bozzi 1990, 341).

In fact, as told by Bozzi, McCloskey and Caramazza – today very well-known and eminent academics – directed their interests towards neuroscience, contributing to the birth of cognitive neuropsychology and neurolinguistics; the fact, relevant for us, remains, of the priority given to the studies of Bozzi on the naive physics. Not only, it is the now dead professor from Gorizia to indicate how the words 'naive physics' recur for the first time with a specific sense of perception in a German book of psychology (Lipman and Bogen 1923);[7] but, obviously, it is not the only recognition of the priority of research and theories that makes important the reading of Bozzi or his intellectual honesty that leads him to answer for what in the meantime others had produced (see Bozzi 1990, 23-65), and not even his undeniable literary charm that he gives generously, managing to enter even in the arid field of the experiment. Paolo Bozzi planned and carried out innovative laboratory research, but above all he was able to construct a theoretical meta-level in which to frame the results and this level is exquisitely ontological and epistemological, because it establishes and tries to find the reasons for naive physics.

In order to verify what it was said above, it is useful to analyze Bozzi's early works in this sense: the one on the pendulums (Bozzi 1958) and the other on the inclined planes (Bozzi 1959), integrating the story with what he recalled several years later (Bozzi 1990).

The first laboratory experience provides for ascertaining, through the observation of a specially constructed pendulum, whether oscillations at various frequencies are perceived as "normal", slow or fast with respect to a hypothetical pendulum free to oscillate; secondly, understanding which factors (different from the only one that affects the pendulum motion, i.e. the length of the pendulum) influence the responses of the subjects. I abstain from proposing again the experimental part in detail (Bozzi 1958, 39-48), on which I believe we can trust, in order to analyzing the results; in fact, it emerges that "the structural laws of the phenomenal pendular movement are quite far from those that regulate the same movement on the physical plane" (Bozzi 1958, 48), they possess an evident Aristotelian connotation that persists despite the repetition of experience and, above all, regardless of the notions of physics possessed. But Bozzi, instead of simply acknowledging the fact, hypothesizes that certain "errors of theorization" found in the history of science find an explanation precisely in the "immediate evidence of the facts" (Bozzi 1958, 29); in other words, ancient and modern science have been, respectively, inspired by immediate experience and contrasted the phenomenal evidence. Indeed, the distinction between "right", "fast" and "slow" – suggested by the experimenter, and simply accepted by the respondents – used to describe the frequency of the pendulum motion, easily reveals the similarity of the distinction that from Aristotle to Galileo "was never questioned by physicists" (Bozzi 1958, 37), that one between "compulsories" and "naturals" movements.

Indeed Aristotle writes: "All movement is either compulsory or according to nature, and if there is compulsory movement there must also be natural (for compulsory movement is contrary to nature, and movement contrary to nature is posterior to that according to nature, so that if each of the natural bodies has not a natural movement, none of the other movements can exist)" (Aristotle 1995, 1, Physics, IV, 215a);[8] and Bozzi reflects on how it is true that this distinction is also based on the need for logical coherence of Aristotelian physics, but the persistence of these "errors" – both in physics and in common sense – "becomes more understandable if we consider it [to be] very [spontaneous], precisely

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[7] In fact, even if "the volume includes, above all, studies carried out on children and animals (and it widely uses the research of W. Köhler about the anthropoid monkeys) [and] the intentions of the authors are mainly applicative and pedagogical [,] it is written on the assumption that the appropriate use of physical objects by animals and man *presupposes* a naive physics (largely not conceptualized or even unconscious) and it develops interesting analyzes of the thought processes involved in such practices" (Bozzi 1990, 28n).

[8] See also Aristotle 1995, 1, *Physics*, V, 230, 29a-31a.

because it reflects our way of seeing reality" (Bozzi 1958, 37). It is in opposition to this way of seeing reality or, if one prefers, against the evidence of the Aristotelian common sense against for which Galileo fights; he does so by opposing his system at an ontological, rather than epistemological,[9] level, thus redefining the relationship with experience before implementing a "new method". In this regard, I consider very incisive the observations made by Bozzi who speaks about a quite paradoxical apparent agreement between Aristotle and Galileo; both seem to agree about the principles of a proper scientific investigation: about the faithful observation of the facts, the systematic nature, the generalization starting from particular cases (the single case cannot be "science") and the pre-eminence of facts with respect to the theory, "at least as matter of principle" (Bozzi 1958, 30). As a partial confirmation of this, he recalls how Galileo, in the *Esercitazioni filosofiche di Antonio Rocco*, firmly affirms that: "If Aristotle lived in our age, he would change his mind: whether his argue was based on the senses or on the experiment, now he would perceive the opposite of what he believed, and he would undoubtedly also conclude the opposite, that is, the skies are corruptible"[10] (Galileo 1633, 617). This agreement, as we can see, is superficial because the opposition is evident on several occasions and firstly they both radically diverge on the way of understanding *the facts of the experience*: Aristotle would be in favor of the common sense, Galileo is, because of his strong limits, in favor of scientific reason; the former gives evidence of an observation much "naïve" than the latter and, correlatively, the degree of abstraction in the mechanics of the latter is of a higher level.

Bozzi's research had not the purpose to analyze the differences between Aristotelian and Galilean science; what interested him was an important feature of the reasoning of the Stagirite, the one that, despite the theory, makes the "you see so-and-so" (Bozzi 1958, 31) prevail; and therefore he wanted to highlight how in Galileo the attempt was in the opposite direction: "sterilizing" reality from naive experience to achieve a "scientific" knowledge. The case of the harmonic pendulum motion confirms this hypothesis; in fact, through his experiments, Galileo understood that the only factor able to influence the frequency of the pendulum oscillations was its length. Not the mass, not the weight nor any thrust can delay or accelerate the motion of the pendulum, the oscillations are isochronous for any amplitude of arc (with much approximation, so much that in physics we speak of isochronism of small oscillations); this, however, seems contrary to the common sense, so much that Guidobaldo Del Monte, first teacher and then colleague and friend of Galileo, had expressed to the great Pisan some perplexities in this regard, as we can realize in the long letter of reply (1602, November, 29) in which Galileo began by apologizing for the insistence with which he wished to "convince you of the truth of the proposition on motions in equal times in the fourth part of a circle; because it has always seemed to me extraordinary, today even more so, that you consider it impossible"[11] (Galileo 1900, 101). Something similar happens in the *Discorsi,* when, in response to an experience repeated several times with pendulums of different material (lead and cork) and equal length, Salviati, the narrator, seems amazed at the result, that is at the isochronism for small oscillations: "Repeating there goings and comings a good hundred

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[9] About this see Koyré 1978. It is clear that, in the continuation of the argument, the interpretative ways of Bozzi diverge sharply from those of Koyré, starting from the role of experience in Aristotle physics, seen by the great French historian as contrary to common sense.

[10] "Se Aristotile fusse all'età nostra, mutarebbe opinione: sia che il suo filosofare ha per base la cognizione sensitiva o esperimentale, la quale ora gli mostrasse l'opposito di quel che egli stimava, senza dubbio anch'ei l'opposito concluderia, cioè che i cieli fussero corrutibili".

[11] "Persuaderle vera la proposizione de i moti fatti in tempi uguali nella medesima quarta del cerchio; perché essendomi parsa sempre mirabile, hora viepiù mi pare, che da V. S. Ill.ma vien reputata come impossibile".

times by themselves, they sensibly showed that the heavy one kept time with the light one so well that not in a hundred oscillation, nor in a thousand, does it get ahead in time even by a moment, but the two travel with equal space" (Galileo 1989, 87). Even Sagredo is amazed in front of the movement of the lamps hanging from the high ceilings of the churches, because increasing the amplitude of oscillations, time was the same, and he says, "I certainly do not believe that I would ever have discovered this, which still seems to me to have in it something of the impossible" (Galileo 1989, 99).

Obviously, when we perceive amazement through the words of Salviati, Sagredo and Simplicio, it is – according to Bozzi – always Galileo to show it, the scientist divided between theories elaborated with accurate measurements and the one with the naive look (see Bozzi, 1990, 278-280) who has made possible "the sketch – visible by looking backlit its mechanics and in general its science – of a new science, of a naive physics, dealing with the experience of the external world suitable for all" (Bozzi 1990, 286);[12] the great Pisan scientist did not sweep aside the secondary qualities (what one immediately "sees"), but he scrupulously recorded them in his writings in order to replace them with "blocks of knowledge operationally and mathematically guaranteed" (Bozzi 1990, 286).

The situations described by Galileo made Bozzi consider their double interest: for the history of scientific thought, as they prove the difficulty of overcoming prejudices well-established in scientific conceptions, and for the psychologist of perception, because they indicate a world "immediately" distinguished by specific perceptual structures, often in contrast with the physical-mathematical data of reality (Bozzi 1993, 32-3). In this second sense, several years later, Bozzi considered as purpose of his research finding "an aesthetic of the pendular motion. In the sense of Kant (perception) and in the current sense, or in the sense of Kandisky" (Bozzi 1990, 268).

To corroborate his hypothesis, the Professor of Gorizia planned a new experiment that strictly carried on the previous one because it replicated what was required to the sample on the pendulum motion in front of balls left rolling on inclined planes. I remember that Galileo had accomplished – according to Viviani – numerous throws of bodies of different material from different heights:

> And then, to the dismay of all the philosophers, very many conclusions of Aristotle were by him [Galileo] proved false through experiments and solid demonstrations and discourses, conclusions which up to then had been held for absolutely clear and indubitable; as, among others, that the velocity of moving bodies of the same material, of unequal weight, moving through the same medium, did *not* mutually preserve the proportion of their weight as taught by Aristotle, but all moved at the same speed; demonstrating this with repeated experiments from the height of the Campanile of Pisa in the presence of the other teachers and philosophers, and the whole assembly of students (Viviani 1717, 606. Trans. Cooper 1935, 26).

In fact, considering the controvertibility of the fact already at that time and the precision by which Galileo described the experiences, it would have been better to repeat a gravity experiment in a phenomenological key, but, in view of the difficulties in its planning (launches from considerable heights with fall times too short to be carefully observed), Bozzi

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[12] On the other hand, Bozzi made no secret, later, of appreciating Galileo who had written ""we see" [...] "we note", that someone shows something to another, and he cannot [...] interpret those sentences if not proposing to [himself] an immersion in those same observations concretely updated and introduced to [his] senses" (Bozzi 1990, 287).

appropriately worked around the problem by opting for motion along the inclined planes, "a particular case of the fall" (Bozzi 1959, 53).

Also in this second research the sample of people was questioned about which motion appeared "normal" and whether it was subjectively "fast" or "slow", trying to understand the reasons. Omitting the details of the execution of experiment,

> The results of this experiment allow [...] to state that the movement of an object along a sloped plane, in order to be phenomenally a good downward movement [neither too fast nor slow, therefore without an external intervention], it must be a movement at the beginning accelerated, until a certain speed is reached, and from that moment onwards it must be uniform. (Bozzi 1959, 60-1).

This result is a clear indication of the presence of a pre-Galilean dynamics; in fact, Aristotle says "…Thus the weightless body will move the same distance as the heavy in the same time. But this is impossible. Hence, since the motion of weightless body will cover a greater distance than any that is suggested, it will continue infinitely" (Aristotle 1995, 1, *On the Heavens*, III, 301b, 12-16).

And Simplicio, the Galilean character, said more precisely: "There can be no doubt that a given moveable in a given medium has an established speed determined by nature, which cannot be increased except by conferring on it some new impetus, nor diminished save by some impediment that retard it" (Galileo 1989, 66).The "resistance" of these Aristotelian notions, generally revealed in the researches on naive physics, is not only present in our time, but also appeared in the age of Galileo; although these were well-established ideas from a cultural point of view, nothing prevents us from understanding in Simplicius' words an authentic movement of annoyance towards those who were to some extent crumbling the world of common sense, for example when he stated: "I shall never believe that even in the void – if indeed motion could take place there – a lock of wool would be moved as fast as a piece of lead" (Galileo 1989, 76).

Between the Aristotelian "seeing" of Simplicius and the Galilean experimentation there are deep differences of an ontological and epistemological nature which from time to time emerge in an evident way; like when Salviati "seriously doubt that Aristotle ever tested whether it is true that two stones, one ten time as heavy as the other, both released at the same instant to fall from a height, say, of one hundred braccia, differed so much in their speed that upon the arrival of the larger stone upon the ground, the other would be found to have descended no more than ten braccia" (Galileo 1989, 66); by "tested" he meant a type of experimentation or scientific approach clearly different from the Aristotelian one; in fact Simplicio answered: "But it is seen from his words that he appears to have tested this, for he says "We see the heavier…" Now this "We see" suggests that he had made the experiment" (Galileo 1989, 66).

At this point, we can consider what naive physics is for Bozzi, aware of the fact that the answer will be more articulated than that given by classical cognitivists; in fact, according to him there are

> two complementary areas that contribute to compose this new discipline: on the one hand the naive physics is a system of beliefs, obsolete but much more coherent than commonly believed, around the properties of inanimate objects present in the world of our experience; on the other hand, it is a system of relationships, largely still to be explored, which connects those beliefs to one another and to the way we perceive the events of the external world, to the appearance of the physical properties of things (Bozzi 1990, 28).

And undoubtedly the perceptual system is not a transmitter of stimuli, a passive receptor of the world designed by physics, rather "it is a complex instrumentation for navigating in life" (Bozzi 1990, 29), that is to say it is a necessary condition for maintaining the biodynamics balance of the body. With this we have reached the limit of the latest generation cognitivism, the one that binds biology and knowledge, life and cognition; but the ideas of Paolo Bozzi, as we have mentioned above, fall badly under predefined boxes: they are interdisciplinary, "eccentric", of analytical inspiration and, ultimately, they lie outside classical cognitivism.

Finally, if naive physics (or "naive physics of a phenomenological type") is "a theory of physical properties of the world directly ascertained, distinct from the "phenomenological" physics of physicists, but almost certainly linked to that one on the historical and genetic level" (Bozzi 1990, 190), it can certainly be useful to consider how much Piaget independently elaborated, in the last years of his life, around the psychogenesis of physical notions in relation to the history of science (Piaget and García 1989).

Piaget: The Children and Early Science

Although it would be very interesting to do so, the Piagetian research cannot be followed here in detail.[13] Its results represent the preconditions for what I will try to show, that is the results on the epistemological level and on historiography of science. Actually, this argumentative sequence is the same that comes out of the entire work of Piaget, in fact in his latest work, written with the physicist Rolando García and published posthumously, the parallelism between the thought of the child confronted with elementary phenomena of mechanics and ancient and medieval science is explicitly treated; a subject whose "epistemological scope" has not been well understood by both psychologists and historians of science. (see Piaget and García 1989, 31-2).

The narrative order, this time, is reversed: it starts, in fact, from an essential overview of the Aristotelian theories of motion, not without a lucid analysis, very useful for us, as in the case of the role of observation by Aristotle in the study of movement: it would be

> direct, rather simple observations, limited by the process we shall call "pseudo-necessity". For example, the only movements he recognizes are rectilinear or circular, hence his absurd conclusions concerning the paths of projectiles. His epistemic positions are thus impaired from the outset, because a lack of experimental data. In contrast, the facts (rightly or wrongly considered such) and the concepts used to express them are related within a system of an impeccable logic (Piaget and García 1989, 33).

In this way Piaget behaves in a different perspective in many ways opposed to that of Bozzi: we are not in the presence of naive observations poured into physics whose imperative force resides precisely in being perceptible by anyone, but of a set of facts superbly reunited in the system whose impeccable logic determined a long lasting success (see Piaget and García 1989, 33 and 58); confirming this sensation, he later wrote: "Aristotle's physics does not take as a starting point the study of certain particular types of motion; instead it proceeds from certain general metaphysical principles. Aristotle does not analyze how bodies descend in free fall (Galileo would do so two thousand years later). He begins

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[13] See, among the other studies, Piaget 1975, 305-336; Piaget 1996, 107-242, 395-437.

with a general observation: *The fact that bodies fall*. Then, he tries to infer how they fall, by means of rigorous reasoning based on metaphysical principles" (Piaget and García 1989, 44; see also 58). The ambiguity of these statements involves the same Aristotle, who is denied the attribute of observational empirical scientist much to the advantage of a metaphysical rationalism which is however implemented by a "general *observation*" (my italics); there would be much to say about the concept of "metaphysics", while it is clear and acceptable the fact that Aristotle elaborated a dynamics, while Galileo approached, not without difficulty, kinematics.

According to Piaget, the doctrine of Aristotle on motion has some fundamental characteristics; first of all the distinction between natural and compulsory motion, the second is contrary to nature and is always subordinated to the first in the sense that "if any of the natural bodies has not a natural movement, none of the other movements can exist" (Aristotle 1995, 1, *Physics*, IV, 215a). The natural motion, then, causes the body to move in the direction of its natural place and, once reached it, it stops until a cause of displacement (compulsory) occurs; the natural movement is generated by an internal "motor", the other always by an external agent, it is however "impossible to move anything either from oneself to something else or from something else to oneself without being in contact with it: it is evident, therefore, that in all locomotion there is nothing between moved and mover" (Aristotle 1995, 1, Physics, VII, 244, 14a-1b). "All motion needs an environment in which the mobile can move about" (Piaget and García 1989, 39), because Aristotle cannot explain otherwise the fact that any body, once launched, continues its motion without any direct contact with the initial cause of the movement; in other words, the movement always requires a direct contact with the engine and if the stone thrown by our hand continues to move after the launch is because the motion is transmitted from one motor to another, from our hand to the air that is in continuous contact with the projectile (see Aristotle 1995, 1, *Physics*, VIII, 266-267, 28b-16a). Consequently, the absolute vacuum and the continuity of transmission cannot exist. Still, the natural motion can only be of two types: rectilinear and circular; the second is perfect because "the circle is a complete thing. This cannot be said of any straight line: – not of an infinite line; it would have a limit and an end: nor of any finite line; for in every case there is something beyond it, since any finite line can be extended" (Aristotle 1995, 1, *On the Heavens*, I, 269, 19a-21a).

Aristotelian theories on motion were criticized since the 6th century A.D. by the John Philoponus; he believed, in particular, that the transmission of movement by a means – specifically air – was to be excluded because the antiperistasis was improbable: how can air be pushed forward by the bullet, go back and push it in turn? If air is the cause of the motion, where is the absolute necessity of a first agent, for example of the hand, in the economy of motion? – Philoponus asked himself – (see Piaget and García 1989, 45-6). If the observations of the Alexandrian philosopher were substantially ignored throughout the Middle Ages, they unconsciously were at the core of the debate in the 13th Century with Buridan and the so-called school of *impetus*.

"Aristotle provides the conceptual framework serving as a frame of reference for all reflection concerning science [, indicates] what kind of question one should ask about motion [and establishes] the kind of "explanation" to look for, having introduced the idea of explaining nature in rational fashion by logical demonstration based on accepted premises (Which, in themselves, could not be demonstrated, however)" (Piaget and García 1989, 47); though the scholastic tradition (Ockham, Grosseteste, Roger Bacon, Wittelo etc.) represents a considerable advance with respect of Aristotle's methodology, the overcoming of his epistemological positions is only partial, "his *Physics* remains the only coherent system for trying to explain the Universe and its phenomena" (Piaget and García 1989, 49). With Buridan and Nicole Oresme the criticism is undoubtedly more pressing; above all the former gives a series of counterexamples based on experience which retract the Aristotelian theories on motion and give rise to *impetus*, that is to a force that is impressed by the motor and stored in the body until extinction. It continues to push the projectile in the impressed direction, it will be directly proportional to the speed of the motor and the weight of the body (see Piaget and García 1989, 50); air no longer plays any active role in the movement, limiting itself to generating only "resistance" on the surface of bodies and the *impetus* also explains the acceleration that a body in free fall shows during the descent (later Oresme, disciple of Buridan, clearly made a distinction between the acquisition of Aristotelian heaviness and *impetuosity*. See Piaget and García 1989, 52-3).

The ideas of Aristotle, even if partially amended by Buridan, were considered the model of scientific thought at least up to Galileo; the Stagirite, according to Piaget, used a great logical rigor starting from necessary premises however unprovable. This type of reasoning was put in correspondence with a precise initial phase of the development of the child's intelligence, the one dominated by the pseudo-necessities and pseudo-impossibilities, and it is a result, in the specific case of the history of mechanics, not of imposing perceptions – as Bozzi suggested – but of cognitive limits and of a social context in which there is a "world view [influenced by] religious conceptions" (Piaget and García 1989, 58).

Another essential passage in the history of mechanics was certainly the introduction of the measure, which marked, from an epistemological point of view, the passage from attributes to relations. If the idea of perfection and incorruptibility had permeated the skies of Aristotle, making them quite different from the Earth, Galileo notes as scrupulously as possible distances and times, and Newton will find in the law of gravitation the synthesis between the celestial and terrestrial world. The transition from attributes to relations is not a prerogative of a certain age: Piaget traces it "in all the important revolution in the field of mechanics" (Piaget and García 1989, 60), from Einstein to Bohr. It "involves nothing less than the substitution of relations of almost "tangible" properties by an abstract system" (Piaget and García 1989, 61).

The parallelism between what is shown by scientific historiography and the development of physical notions in the child is clear, according to Piaget; Aristotle had elaborated the theory of the two motors (one external and the other internal to the body) to explain the motion and many people consider it necessary for a body to move on an internal motor and a continuous contact with the external movement. For example, "very young children [...] may believe that the wind is produced by trees (which sway by themselves), by waves that rise, or by clouds which spontaneously move ahead. This naturally favours the formation of the antiperistatic schema" (Piaget and García 1989, 67-8). In a second phase we assist to a loss of importance of the internal motor (even if it does not disappear) to the advantage of a single driving force. It finds a psychogenetic correspondence in the "disappearance of the internal motor; at this point, a certain number of powers are bestowed on the external movement" (Piaget and García 1989, 69) not yet differentiated.

The third phase, in which the rush or *impetus* is caused by the force that produces the motion, and it is a necessary middle term between force and trajectory (as in the medieval reform of Buridan and Oresme) represents the prelude to the fourth and last in which *impetus* is substituted by acceleration, this happens with the birth of classical mechanics. Here the child gradually discovers, thanks to an effort of quantification and to the maturation of abstraction capacity, that the variation of speed and not the 'rush' generates the movement (see Piaget and García 1989, 67-74). An example can be useful in understanding the stages above considered, that "is that where the transmission of motion is seen as mediated by immobile elements" (Piaget and García 1989, 69):

> A marble hits a block and initiates movement in another marble on the other side of and contiguous block, or it may hit the first of a row of marbles only the last of which will be set in motion. In stage 1, subject still appeal to an internal motor: the marble hits the block, which remains immobile; but the marble on the other side starts by itself by a kind of contagion and by its own force. In stage 3, subjects say that the active marble, because of its force, give an impetus which passes "across" the intermediate elements and provokes the passive marble into motion. But in stage 2, the internal motor is eliminated, but the intermediate impetus is not yet differentiated and the active marble is seen as the source of some "global action" […]. While the impetus was seen as the cause of motion and velocity during stage 3, the relation is now inverted. The impetus is now [*stage 4*] regarded as resulting from velocity or, more precisely, as being one aspect of it. This then tends toward the notion of acceleration. Thus, as soon as subjects witness the mediated transmission, there are some 11-12 years-old who say "it's because of the speed, and because there is more and more speed, because the marbles (in the row) transmit it to each other, there is more impetus". [And more,] "the force is transmitted from one marble to the other" (Piaget and García 1989, 69-72).

Further examples taken from the Piagetian experimentation on the subject can be found in Piaget 1930.

Final Remarks: Aristotle the Revenant

This paper has not the purpose of analyzing affinities and differences between the interesting proposals of Bozzi and Piaget; however, I would like to recuperate some epistemological issues that may arise from what has been analyzed up to now.

The history of science emerges in all the researches here evaluated, but in a very different way: the cognitivist psychologists had the merit of bringing at the core of the debate an issue so far passed quietly, but limiting themselves to "recording" that the Aristotelian theories of motion were always present in the explanations of the examined people; therefore, they generally[14] did not make any organic connection with the history of science except from using it in reference to the results. In Paolo Bozzi, instead, there is an explicit, conscious and recurrent use of the history of science, even if subordinated to the onto-epistemological aspect. But it is with Piaget (who takes up an idea expressed in Dijksterhuis 1959, 182-4) that the history of science "constitutes not only the memory of science, but also its epistemological laboratory" (Piaget and García 1989, 55). In other words, Piaget connects the evolution of scientific thought to the psychogenetic one of the child, not using history as an element of the "context of discovery", not as a "catalogue" of experiments.

In light of what we have considered up to this point, I recall that according to Piaget, the persistence of Aristotelian ideas on motion has traditionally been attributed to a lack of observation; in other words, the historians of science – at least for the most part – saw in the observation and experimentation of Galileo and Newton the main character of classical physics, the turning point through which it developed. He, however, posing himself on a different level, wrote: "We shall defend the thesis that the difference between the ancient and the modern science is no way lies in a willingness or unwillingness to resort to empirical

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[14] An exception, in this sense, is represented by Nersessian 1995 who, however, decisively takes a direction different from the history of classical science, trying to outline a new one for the future.

observation, nor in the use of or abstinence from deductive methods. The explanation has to be sought elsewhere" (Piaget and García 1989, 45).

The Gestaltist Bozzi, to whom we owe the first studies on naive physics, draws from his research a new realism and a new "aesthetic" in which the cognitive aspect is never prior, but rather the sensorial one; a lens through which he reads the history of science in an epistemologically opposite way as for Piaget. The latter, in fact, firmly believes that first a minimum of cognitive skills are formed (rooted, in turn, in biological functioning) and then knowledge is built; according to Bozzi we have a perceptual system with a certain functioning and scientific knowledge is built in contrast to what we see or touch: what comes to us from the senses is the reality of which we immediately have a naive physics.

Bozzi, moreover, does not seem to see any evolution of the perceptual system in the long term (human beings have perceived, and they always will perceive in the same way), his perspective is synchronic ("here" and "now") in which one can study the statements of science as the result of the imposition of a cognitive supra-structure on the phenomenological. According to Piaget the roots of knowledge are in the logical (and biological) field; according to him any theory about children on reality – from the most trivial to the most sophisticated – went through the construction of a "methodology derived only from [...] logical reasoning rather than experimental expertise or pre-existing theoretical knowledge" (Piaget and García 1989, 83). More clearly, he states that any empiricism is unsustainable because "there is no such thing as "pure" perception or experience. The "reading" of experience requires the *application* of cognitive instruments – which make it a reading – as well as the *attribution* of relationships between objects – which furnish the causal links between events" (Piaget and García 1989, 247).

In general, then, it is the invention of new problems that makes new methods apply to the physical reading of reality, or better: the scientific method "was subordinated to the world view and the nature of the problems raised" (Piaget and García 1989, 185) and not vice versa;[15] this is why the historical or historiographical dimension, the reconstruction of the conceptual frameworks of an era or of a culture, are essential not only for the understanding of physics, but also for its "internal" epistemology in that they present evolutionary mechanisms similar to those of cognitive process of individuals.

I still remind that according to the Swiss psychologist-epistemologist, "the history of mechanics (from Aristotle to Newton) could be described as a history managed by the process of eliminating pseudo-necessities" (Piaget and García 1989, 59). Moreover, this process, from a psychogenetic point of view, consists in a progressive construction of schemes through "empirical" and "reflective" abstraction, increasingly sophisticated and logically coherent schemes in which

> at each level, certain previous constructions remain in acceptance while other new constructions are elaborated. This is true both for the child and for the quantum physicist. What is characteristic of the process is that at each new level, there is a return to the "level of experience". Each new level is equipped with new interpretative schemata, which enrich the original notions used in the construction of that level (Piaget and García 1989, 204).

In my view, the Piagetian epistemological perspective appears to be the richest, both in terms of content and in terms of analysis. In fact, Piaget and García present a wide

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[15] See also Piaget and García 1989, 80-3. This idea is not new, Piaget notes it by a quote as it had been noted very well Alistair Crombie (Crombie 1995, 291).

historical-epistemological reconstruction not only of mechanics – the subject discussed here – but also of algebra and geometry; a reconstruction generally more articulated than that one we find in Bozzi, who, although he was as good as them in analyzing the specific question of motion in the light of Aristotle and Galileo, reaches ontological conclusions – and only secondarily epistemological – considering the perceived reality valid respect to every possible cognitive "adulteration".

But if there is a connection between the approaches and studies examined so far, it is undoubtedly represented by Aristotle and his physics: cognitivist psychologists, physicists interested in teaching, the phenomenologist Bozzi and the epistemologist Piaget all agree that children, young people, students and the layman, questioned on basic mechanical issues, show typical solutions of Aristotelian physics (in its original version or in the medieval version of Buridan and Oresme); and all, or almost all, seem to agree that these answers are, within certain limits, separate from the studies carried out and the notions possessed.

Definitely, it is true that in most experimental studies there is no mention of possible origins of this strange thing or they give rather banal answers (perhaps because they are considered "deviant" errors from a scientific point of view); Bozzi is an exception because he provides an answer that may seem disorienting (senses provide us with a model of phenomena, prior to any intellectual knowledge), but he is original and stimulating; Piaget explains the experimental findings within genetic psychology (as the result of an incomplete construction of cognitive schemes or appropriate logical tools) and identifies an important epistemological parallelism between the stages of psychological development of children and some phases of scientific thought as they appear in the history of science.

In light of this, waiting for further research to tell us what the "right" direction is (strictly experimental or phenomenological or epistemological etc., or some mix of the previous ones), we can start working on one thing: investigating, explaining or clarifying naive physics could be useful for all those interested in science teaching, to design a more effective teaching method that does not aim to correct the "distortion" of the data, but instead leverages the presumed "errors" and scientific historiography to construct explanatory models of classical mechanics (Galilean and Newtonian) and of physics in general. In fact, you learn more from mistakes than successes, learn more from the "Master of those we know" and not, directly, from quantum mechanics.

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