TEXTBOOKS, FOUNDATIONS, HISTORY OF SCIENCE AND SCIENCE EDUCATION

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Dear Readers,

In history of science we have significant examples of textbooks written by professional scholars, researchers during their teachings job. Thus the research (on foundations of science) and pedagogical aspects are presented, but not at all of them in the same way. Many and various factors are included. Without going too much back, one can consider the newborn theories of heat and thermodynamics and related textbooks used at the end of the 19th century: Jean Baptiste Joseph Fourier's (1768–1830) *Théorie analytique de la chaleur*[1]) and the positivist Gabriel Lamé's (1795–1870) *Leçons sur la théorie analytique de la chaleur*[2] focusing the physical–mathematical relationship in the theory of heat and without considering experimental aspects of the scientific process of knowledge. The physical problem, e.g., between *chaleur* and *calorique* and the second principle are avoided. Therefore Reech's *théorie général des effets dynamiques de la chaleur*[3], in which he adopted and generalized Sadi Carnot's (1796–1832) – and Clapeyron's (1799–1864) – reasonings in order to obtain a general formula from which each of the two theories (on caloric and on heat) can be derived under the right conditions. An Italian scholar Paolo Ballada (1815–1888) also called Paul de Saint–Robert published (at the time into French language) one of the first textbooks *Principes de thermodynamique*[4] on the subject that included scientific studies, as well, as historical part and a first biographical notes on Sadi Carnot and others scholars. The second principle is very much emphasized. Just to mention: Zeuner, Verdet, Hirn, Combes, Clausius, Jacquier, Jamin. Most recently

> Textbooks, however, being pedagogic vehicles for the perpetuation of normal science, have to be rewritten in whole or in part whenever the language, problem–structure, or standards of normal science change. In short, they have to be rewritten in the aftermath of each scientific revolution, and, once rewritten, the inevitably disguise not only the role but the very existence of the revolutions that produced them. […] Textbooks thus begin by truncating the scientist's sense of his discipline's history and then proceed to supply a substitute for what they have eliminated. Characteristically, textbooks of science contain just a bit of history, either in an introductory chapter or, more often, in scattered references to the great heroes of an earlier age. From such references both students and professionals come to feel like participants in a long–standing historical tradition. Yet the textbook–derived tradition in which scientists come to sense their participation is one that, in fact, never existed.[5]

Up to now, it seems that the didactics of mathematics, physics and chemistry have

1 Fourier, J. B. J. (1822). *Théorie analytique de la chaleur*. Firmin Didot Paris.

2 Lamé, G. (1861). Discours préliminaire. In: Leçons sur la théorie analytique de la chaleur, Mallet–Bachelier, Paris. *Id.*, (1861) Leçons sur la théorie analytique de la chaleur. Mallet–Bachelier, Paris.

3 Reech, F. (1853). Théorie général des effets dynamiques de la chaleur. *Journal de Mathématiques pures et appliquées* XVIII: 357–378; *Id.*, (1854) Théorie général des effets dynamiques de la chaleur. Journal de Mathématiques pures et appliquées. Bachelier, Paris.

4 Saint–Robert, P. (1865). Principes de Thérmodynamique. Cassone, (Ed) 1st edn, Torino [1870. 2nd edn. Loecher, Turin et Florence; see also idem edition printed by Gauthier – Villars, Paris]. See also his article on the role played by force in the history. *Id.*, (1872) Qu'est–ce que la force. La revue scientifique de la France et de l'étranger. 2s, Tome II. Germer Baillière, Paris, pp 985–993

5 Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. The Chicago University Press, Chicago, pp 137–138, line 23.

generally proceeded according to the strict assumption that in schools (especially secondary high schools) the teaching of a major amount of mathematical and physical of principles and mechanical exercises only, as well as of mere experiments, is required, regardless of the possibility in their learning process. Teaching so conceived, seems to be the natural inheritance and, let us say, the consequence of a perspective typically mechanicist–positivist and, in some aspects, mechanist of science. A question may be: *what is the constitutive character of science that we teach? Is it the same of the original theories?*

> *The logics of minimal structures of scientific disciplines is different from our way to reasoning, link ideas...et al... too much "fuzzy".*
> *It is not necessary generalize disciplines, it could be – at first step – sufficient to think to re-focus on historical/interdisciplinary cognitive objectives.*
> *It could be interesting to build the capacity of abstraction in pupils by means of multi-values logics.*
> *At school: it should be able to mediate between logics-rigor of scientific disciplines and the uncertainness of human reasoning*

Many European education centres and history of science institutions like the symposia presented in *European Society for the History of Science* congresses, and the *Inter–Divisional Teaching Commission* of the *Division of Logic, Methodology and Philosophy of Science* (DLMPS) and the *International Union for History and Philosophy of Science* (IUHPS) are reflecting brilliantly upon higher scientific education and its improvements in secondary level. It is unthinkable to learn and understand the scientific sense of a subject without deepening its intellectual and cultural background, e.g. history and its foundations: *how is it possible to keep on teaching sciences being unaware of their origins, cultural reasons and eventual conflicts and values? And how is it possible teaching and remarking the contents and certainties of physics and mathematics as sciences not having first introduced the sensible doubt about the inadequacy and fluidity of such sciences in particular contexts?*

On my side, focusing on mathematics, physics and its relationship, a larger base of analysis should be adopted. It should include not only disciplinary matters but also interdisciplinary issues among history, historical epistemology, logics and foundations of physical and mathematical sciences. A multidisciplinary teaching based on large themes–problems toward a scientific education based on different formulations of the same theory would be appreciated. Some of the following case–studies may be discussed reading a textbook related with history of science: E.g., lack of relationship physics–logics, space and time in mechanics, mechanics and thermodynamics, *ad absurdum* proofs, non–Euclidean geometries and the space in physics, planetary model and quantum mechanics, infinite–infinitesimal and measures in laboratory, heat–temperature–friction, and reversibility phenomena, concept of set and field, continuum–discrete models in mechanics and theory of elasticity of the 19th, hypothesis *ad hoc* in the theory, local–global interpretation and differential equations–integral, point–range and physical phenomena, mechanics, kinetic model of gases and thermodynamics. For example a cultural role played by using a textbook based on history of science and science teaching may be:

> *The mechanization also changed the image of physical world. Is it important for science studies teaching?*
> *What is the constitutive character of science that we teach? Is it the same of the original theories?*
> *The modeling is really only unique bridge between experiments and theory?*
> *Does we also teach the relationship among scientific theories?*
> *We teach rigor and regularities interpreted by a kind of mathematics. Is it possible to include also irregularities among theories?*

E.g.: The irreversibility: if we delete the friction… do we come back to mechanical phenomenon?
E.g.: Trajectory and probability in classical mechanics and quantum mechanics…
E.g.: The tentative axiomating in Special Relativity…

In the following two concise examples[6] of activities.
Galileo (1564–1642), unlike Leonardo da Vinci (1452–1519) was interested in the deformation of beams and studied the resistance of cantilevers and their capacity to fail down. Galileo proposed his statics in two works, *Discorsi e dimostrazioni matematiche* and in *Le Mecaniche* which also contains an extensive *Appendix* pertaining to physical–mathematical theory on of the centre of gravity. The *Appendix* appears as an independent work in *Opere di Galileo Galilei* (Galileo 1890–1909) and is entitled *Theoremata circa centrum gravitatis solidorum*. It is probably also the antecedent to *Le Mecaniche* although the date of its composition is not well–defined (fl. 1585–1588). In these works, Galileo's approach is Aristotelian when he proposes virtual speed and adopts the Archimedean theory on centres of gravity. However, in general, he is able to adopt both dynamic and mathematical approaches without producing contradictions. The *Theoremata* is based on *ad absurdum* proofs and the theory of proportions. Galileo works on centre of gravity of a composed balance associated in an ideal geometric composition. By means of an (ideal) experimentation and proportions, he positioned, in turn, *1, 2*,… *n* bodies hanging scales and for them (each time) calculated by the centre of gravity, then comparing the results obtained and finally, re–applied the ratio by dividing the entire balance in two parts obtained by last two proportions calculated...and so go on. In this way he obtained the centre of gravity of the balance imagining geometrically composed by two virtual balances, each of which consists of a certain number of magnitudes hung (*appese*). Regarding the expression *punto di equilibrio* and *centro di gravità*, we could assume that Galileo meant that the centre of gravity could balance (which mathematically would reset) dis–equilibrium implemented by the forces–weight–you can imagine made geometrically.

Mysterium Cosmographicum (1596) was the first work written by Johannes Kepler (1571–1630). The young astronomer declared to be Copernican, but with surprise (and probably Galileo himself was the first to be surprised), after the introduction, the main subject of the book does not consist in a series of proves in favour of the Copernican system and against Ptolemaic and Tychonic systems. Rather, Kepler proposes a model of the solar system based on the idea that the spheres (to be interpreted as mathematical, not physical entities) of the planets were inscribed in and circumscribed at the five Platonic polyhedrons. Each sphere was inscribed in and circumscribed at two different polyhedrons. This way he provided a model of the solar system. According Bussotti (Pisano and Bussotti) his ideas were involved with metaphysics and likely this was why Galileo, after an enthusiastic answer concerning the introduction to *Mysterium*, did not prosecute the discussion with Kepler on this book. However *Mysterium* offers a plurality of interesting perspective in the history of science: 1) Kepler tried to confirm his theory with the data deriving from the observations of the astronomers. This way he showed that his construction is consistent with the data provided by Copernicus as to the relative distances between celestial bodies and proved that with some further considerations (for example considering that the lunar sphere makes the radius of the earth sphere bigger) tried to prove that the coincidence between data and theory was still better; 2) the idea of Kepler was – starting from *Mysterium* – to provide a physical, not only cinematic, model of the solar system. Hence Kepler spoke – despite in a naïve and not precise form – of a force which maintains in equilibrium the solar system. He observed that to have a precise idea of this force, to measure it, experiments are necessary. Therefore, from a teaching standpoint, we have a very

6 It regards with Pisano and Bussotti's large article–forthcoming. The focus is on an epistemological standpoint concerning the role played by experiments in Galileo and Kepler (Pisano and Bussotti).

interesting picture: Kepler was a theoretician and, for some aspects a metaphysician, but at the same time his aim was to find a real form of the solar system. Therefore, in his conceptions there is a perfect understanding of the importance of experiments and observations. These are also the reasons why, after *Mysterium*, he reached the idea that the orbits of the planets are ellipses: a hard work of observations and calculation is behind this discovery.

Two case–studies: 1) the role played by dialectic of mathematics–physics relationship to show that Galileo wrote *Theoremata* – compared to the mechanical works cited – strictly following the Archimedean idea of experimentation and method of composition and de–composition and not as a primitive cognitive process on the improbable theory of a system of bodies. He used Archimedes' method compositing circumscribed and inscribed figures, each of which has its own centre of gravity. Then, the centre of gravity of the figure made by Galileo is found, in fact, through an algebraic–geometric result obtained by calculating the ratio. 2) The complex net of relations which, in *Mysterium*, tides the experimental part of astronomy with theoretical and, in case of Kepler, the metaphysical one. After the descriptive part we would like to understand why Kepler reached such a strange, genial and original connection between "practice" and "theory". Thus, didactic and foundational aims are to give a contribution to the study of the relation between physics–mathematics–metaphysics and between experiments–observations–theory in two scientists, as Galileo and Kepler, who were two of the "fathers" of modern science.

A debate and suggestions among science scholars, teachers and historians on the matter seems indeed necessary from an ethic and professional point of view. On my side I remark: *what kind of scientific cultural background does it take to teach how science works?* Then, to move towards a larger base of analysis which includes not only disciplinary matters but also sociology and epistemology seems plausible. It is remarked that teachers regularly find crucial difficulty to teach historical, sociological, and philosophical knowledge about science in ways that their students find meaningful and motivating. It is unthinkable to learn and understand the scientific sense of a subject without deepening its intellectual and cultural background, i.e. its history and foundations. Education needs to revaluate scientific reasoning as an integral part of human culture that could build up an autonomous scientific cultural trend in schools. Thus, in order

> To foresee the future of mathematics, the true method is to study its history and present state.[7]

Thus, what about the importance of

> *introducing the history of foundations of science as an essential part of the culture of teaching education to the extent of considering such a discipline – in its turn – as an indissoluble pedagogical element of history and culture?*

And in this sense,

> *by introduction of history of foundations of science, how can the role played by textbook for secondary school change?*

Thus, if a textbook change,

7 Julius-Henri Poincaré quoted in: Klein, M. (1980). *Mathematics. The loss of certainty*, The Oxford University Press, p 3; *Id.*, 1972. Mathematical Thought from Ancient to Modern Times, the Oxford University Press; *Id.,* (1968) La Science et l'Hypothèse, Flammarion, Paris.

how the teachers should change? What kind of profile?

Finally, as I suggested in a previous *history of science & science education* standpoint work[8] we should move toward a new professional teacher: teachers that teaches research and publish. *We should not lose the certainty*[9] *of a critical thought on science...* turning from *teaching based on principles* to *teaching (also) based on large and cultural foundational themes*[10] related with *ad hoc* foundations–sociological–epistemological aspects of science.

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Received: *November 11, 2011* Accepted: *November 18, 2011*

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