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Energy: Learning from the Past

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Today "energy" is one of the most widespread terms in popular and scientific use. Both enthusiasts and opponents of contemporary Western civilization recognize its foundational role (Ostwald 1908; Heidegger 1953a). Eastern philosophies of Nature have terms that are related to it (Needham and Wang 1956). "Energy" issues dominate social, political, technological, military discussions and events. However it is not at all clear if its various meanings are acceptable aspects of its polysemic nature or the result of deep confusion. Is there a way to clarify the field?

1 Energy and Natural Philosophy

History can provide some help. We can share with the radical criticism of our civilization the suggestion to go back to the origins (Heidegger 1953b): in our case to the Presocratic discussions on *Becoming* and *Being* in the delineation of the *Physis*, the first natural philosophy to oppose myths and religion. Here we find some useful hints: the difference between *stoicheion* (Thales: Diels and Kranz 1951, DK, 11A13a) and *archè* (Anaximander DK 12A9), or the idea of the distinction between an elementary substance and a principle of action, and the *ex nihilo nil fit* together with the *nihil fit ad nihilum* (Parmenides DK 28B8; Melissus DK 30B1-2; Empedocles DK 31B11; Anaxagoras DK 59B17), or the principle that nothing can be created or destroyed (see also: Aristotle *Metaphysics* Book 1). One of the so-called energy pioneers, Robert Mayer (Mayer 1845 in Lindsay 1973, 1975), makes explicit reference to this principle, which is widely discussed in a famous treatise by Planck (1887).

According to the Presocratic pluralists, *Becoming* can be explained through aggregations and separations of underlying stable elements. The atomists' approach is the most famous and long lasting of all and even today the *De Rerum Natura* (Lucretius), the Latin poetic version of atomists' philosophy, astonishes and inspires. Aristotle's contributions to the analysis of the cause-effect relationship, as well as his distinction between potentiality

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and actuality are certainly at the root of our understanding of “energy”, a term which he is the first to use (Aristotle *Physics* Book 1 part 3, *Metaphysics* Books 1; 9).

Being seems to be a greater concern than *Becoming*, and the search for equilibrium conditions leads to the early development of the principle of virtual velocities (Hiebert 1962; Jammer 1963, 1967). The attempt to quantify qualities brings long-lasting results in the fourteenth century with the work of Oresme of Paris (Murdoch and Sylla 1978): the two-dimensional diagrams of the latitude of forms and the distinction between intensive (non additive) and extensive (additive) quantities is at the root of later factorization approaches to understanding energy and permeates the work of Rankine (1855) as well as Maxwell (Maxwell 1871b, 1873) and the famous equations of Gibbs (1876–1878). It is fundamental to the energetic movement at the end of the nineteenth century (Helm 1898; Ostwald 1908) and is prominent in the work of neo-Aristotelians like Duhem (1906) and twentieth century physicists like Sommerfeld (1952).

Becoming returns with the long-lasting search for a perpetual motion machine, rejecting the *ex nihilo* and the *ad nihilum*: why cannot a continuous source of effects without a corresponding compensation be found on Earth if, in the Aristotelian view, the Universe is constantly provided with capacity for movement by a divinity? This search lasts from the twelfth to the nineteenth century and an occasional diehard believer can still be found today, but the results are a long series of failures. However it is not easy to refute the possibility of a perpetual motion machine on theoretical grounds (Planck 1887). Among the first who dare to do so are Leonardo da Vinci, Cardano, Stevin (in Lindsay 1975).

With the latter something new happens, bringing about extraordinary consequences: assuming the impossibility of perpetual motion, new physical laws can be found (equilibrium on an inclined plane). Galileo enters this story with his analysis of the constrained pendulum; Huygens’ generalization to physical pendulums produces the first conservation law: mv^2 for a given system is conserved in specific positions, independently of the internal constraints and the trajectory followed (Bevilacqua et al. 2006).

Soon Leibniz generalizes this result: in a famous short paper he defines it as the true measure of “force” (Leibniz 1686). In his demonstration he assumes the impossibility of perpetual motion and of its opposite (*ex* and *ad* again) and refers to the pendulum experiments. Later he names this quantity *vis viva*; the *vis viva* and the *vis mortua* (which lacks a quantitative definition) have a causal connection: infinite applications of *vis mortua* in a fall produce a corresponding increment of *vis viva* (Leibniz 1695). This causal connection now implies a new meaning of conservation: something is conserved during motion and not only at specific positions. But Leibniz’s contributions go much farther: he expresses the idea that all natural phenomena should be measured. But which is the appropriate unit of measurement? The impossibility of perpetual motion and of its opposite assure us that effects in space (later: *travail*, *work*) are the invariant unit of choice. Thus one of the most ambitious projects in natural philosophy is launched (Cassirer 1906–1907, 1910).

Boscovich proposes a continuity law to unify all natural phenomena, alternating repulsive and attractive forces that depend on the distances between immaterial point-like atoms (Boscovich 1745, 1763). He is also the first to clarify that the *vis viva* controversy was about effects measured in space versus effects measured in time (Costabel 1983). While the Cartesian quantity of motion (effects in time) is at the roots of the Newtonian relation between force and acceleration and won the day in the 18th century, in the long run it is the Leibnizian conception (effects in space) that proved more fertile. The debate was not solved by formal clarification because, as Planck remarked, the origin of every movement in the world was at issue, a veritable philosophical research programme (Planck 1887).

Interesting developments follow: on one side mathematical physics gives birth to the concept of potential, a scalar function from which the force vector can be derived (Kline 1972), and on the other French engineers underline the relevance of the work concept (Grattan Guinness 1984, 1990; Darrigol 2001). From now on, in the work—*vis viva* equation, the stress is on the first term and the factor ½ is added to the *vis viva* term. From a heterodox approach involving "tension" Volta derives the potential contact between two conductors (now motors of electricity) and uses for the first time the term electromotive force. The battery stimulates research on all sorts of interactions and correlations between phenomena and Volta even influences some tenets of Schelling's romantic philosophy of nature (Moiso 2002). Carnot offers a basic theory of thermal machines based on the notion of heat as a caloric substance (Fox 1978).

The search for unity among the various phenomena leads to a principal question: can a constant coefficient of conversion be determined? More specifically: is the conversion between a given quantity of heat and a given quantity of work independent of the way in which it is achieved? This is a very problematic question, because in principle we cannot be sure to know and keep under control all the possible interactions during the conversion. Mayer (1842, 1845) and Joule (1843), among others, give a positive answer and a reasonable numerical value utilizing opposite methodologies: Mayer reinterprets old data in one ideal thought experiment explicitly on the basis of the *ex* and *ad*, while Joule performs numerous real and innovative experiments but utilizes averages of sometimes conflicting results owing to his belief that "God's fiat" is indestructible (Joule 1843, 1845, 1847). It takes almost 40 years to reach with Rowland (Rowland 1880) a critical assessment of the multiple attempts by various authors: the determination of a constant conversion coefficient is hardly a "discovery" and even less so a "simultaneous" one (Kuhn 1959).

Soon after Mayer and Joule, but with a totally new approach, Helmholtz offers his powerful contributions whose relevance endures today (Helmholtz 1847; Bevilacqua 1993). First he identifies, possibly for the first time, theoretical physics as a different playground from the experimental one: while the latter deals with the laws that fit natural phenomena, the former deals with the agreement between general principles and laws. He realizes that principles can have differing formulations and he states his version of the conservation principle as depending on two general assumptions: on the impossibility of perpetual motion, and on the Newtonian concept of force acting at a distance and depending only on (the inverse square of) the distance. Stressing a neo-Kantian concept of causality he gives a methodological contribution of the first rank: the refusal of vitalism and the acceptance of a conservation principle based on the cause-effect relationship is nothing but a precondition for the possibility of scientific knowledge. Helmholtz thus successfully unifies the Newtonian and Leibnizian traditions: on one side utilizing Newtonian force on the other establishing a causal connection between *vis viva* and the sum of tension forces, his reinterpretation of *vis mortua*. While he uses, like Boscovich, effects in space (space is the abscissa, force is plotted on the ordinate, the infinitesimal area is the tension force) his introduction of a new theoretical term like the sum of tension forces (soon after renamed "potential energy") is remarkable: he could have borrowed "work" from the engineers, or "difference of potential" from the mathematical physicists. Here energy and its conservation acquire a first definite (mechanical) meaning: while a variation of potential energy corresponds to a variation of kinetic energy, in every instant the sum of potential and kinetic energy is constant.

This formulation is still widely used in today's textbooks. *Being* achieves a great victory over *Becoming*: something is conserved in the midst of change (Lindsay 1975). In the same paper Helmholtz applies the kinetic-potential energy distinction to the different branches of physical knowledge and hints at biological applications. His final statement is equally impressive: the future task of the physical sciences has to be the corroboration and generalized use of the energy conservation law.

Mayer, Joule and Helmholtz are rather young when they first write on “energy” conservation issues: Mayer and Helmholtz are trained in medicine, Mayer (Caneva 1993) and Joule (Cardwell 1989) are not in an academic environment. Initially all three have their papers rejected.

Helmholtz is well aware that assuming forces that depend only on distances is a necessary condition for defining an energy conservation principle that sharply divides positional (potential) and kinetic terms. In fact in his paper he criticizes Weber’s well-known and widely accepted elementary law of electrodynamic forces depending not only on distances but also on velocities and accelerations. Of course Weber, but also Clausius, deeply disagree: they propose alternative formulations of the principle and a main general tenet: to have conservation we do not need to divide positional and kinetic terms but only need to be in agreement with the impossibility of perpetual motion: in other words the work done by the assumed forces has to be an exact differential. 26 years of bitter controversies end with Maxwell’s acknowledgment in the *Treatise* that Weber (and Clausius) are right (Maxwell 1873). Thus electrodynamic (or electrokinetic, or generalised) potentials, where kinetic and positional terms cannot be divided, are fully acceptable. “Conservative” forces are not only the Newtonian ones (Bevilacqua 1983, 1994).

Clausius (Cardwell 1971) and W. Thomson (Smith and Wise 1989) readjust Carnot’s theory, based on the conservation of the caloric substance, to the new paradigm: degradation of energy and entropy make their appearance, marking the birth of another long-lasting conflict: can irreversible phenomena be reduced to reversible ones or are they a primary aspect of nature? Does time have an arrow? Once again *Being* and *Becoming* compete for supremacy.

2 Energy and Theoretical Physics

After Helmholtz’s groundbreaking paper, Theoretical Physics, as distinct from Mathematical and Experimental Physics, receives its institutional setting. Foundational debates characterize the last quarter of the nineteenth century: the electromagnetic, the thermodynamic and the energetic worldviews challenge the mechanical one (Jungnickel and McCormmach 1986; Bevilacqua 1995). During these debates a number of masterpieces on the history and meaning of energy conservation principles are published.[1] Their reappraisal would be of great benefit even today.

I will confine myself here to one example. In Planck’s 1887 treatise we find, among others: an assessment of why the Leibniz-Cartesians controversy outlasted its formal clarification; of Carnot’s theory as fully within the energy conservation framework, even if he assumes a model of what is conserved that has been abandoned; of the problematic theory–experiment interplay in Helmholtz’s applications of the energy conservation principle (sometimes they were wrong); an analysis of energy as the numerical, objective, mechanical measure of external effects in a given transformation; a consideration of the benefits of the various theoretical possibilities of interpreting energy as an internal

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[1] See for example, (Maxwell 1871b, 1876; Mach 1872; Stewart 1874; Rühlmann 1881–1885; Stallo 1882; Mach 1883, 1896; Planck 1887; Helm 1887,1898; Hertz 1894; Poincaré 1902; Haas 1909; Ostwald 1908; Meyerson 1908; Cassirer 1910).

quantity; an interpretation of energy as a state function; a principle of superposition of independent energy forms; a derivation of energy conservation from the impossibility of perpetual motion and of its opposite (*ex* and *ad*); a discussion of why a primary (final, complete) expression of energy conservation is impossible.

The final pages are extraordinary: Planck recognizes that from an experimental point of view, the electromagnetic theories of delayed action at a distance and contiguous action are indistinguishable: time delay is a common feature. But he asserts that, all the same, a choice can be made on theoretical grounds: an evaluation of the different expressions of the energy conservation principle. His choice for the contiguous action theory is based on two deeply philosophical assumptions: the first is simplicity, the second a refusal of teleology (finality). In fact Planck underlines that the possibility of analyzing separate parts of the world offered by the contiguous action theory (Poynting's theorem) provides a great simplification, especially in the case of time delays. He even forecasts an overturning of the Newtonian gravitational action at a distance theory in favor of a contiguous action one (30 years before the General Relativity Theory). He then asserts that, in the history of knowledge, the assumption that past events influence future events only through continuous infinitesimal steps is a great achievement: teleology has been discarded. Planck believes that the same assumption should be applied to space: action at a distance has to be discarded, interactions can only propagate contiguously in space (Bevilacqua 1983). Here in my view we find an explanation for the deep aversion of Helmholtz and his two associates, Hertz and Planck, towards Weber's approach: the fear of romantic *Naturphilosophie*, with its interconnected unitary world experience, still loomed large.

Maxwell's works provide interesting hints on the complex relationships between mathematical theories and energy physics. He is fully aware that specific theories require specific mathematical tools (e.g.: contiguous action requires differential equations, while action at a distance integrals) (Maxwell 1873 par. 95a). But he also plays a role in the quaternion versus vectors debates. Aware of Hamilton's work on the complex numbers called quaternions (but also somehow of Grassmann's *Calculus of Extensions*) he utilizes them but ends up stressing the separate notion of their scalar and vector parts (Maxwell 1871a; Kline 1972). He introduces the "convergence" (later: divergence), the curl and the "concentration". Recalling Rankine he considers energy a scalar quantity derived by the product of two vectors. "The division of energy into vector factors affords results always capable of satisfactory interpretation. Of the two factors one is conceived as a tendency towards a certain change, and the other as the change itself." (Maxwell 1871a, 1873 par. 35). He also defines "Forces" the vectors referred to the unit of length ("when the integration is independent of the path of the line ….is called a Potential") and "Fluxes the vectors referred to the unit of area." In the *Treatise* Maxwell shows that energy can be equivalently expressed through volume and surface integrals. His famous equations for electromagnetism are expressed in vector components, but soon after are rewritten by Heaviside in vector form (Kline 1972). It is a champion of the vectorial approach, Gibbs, who leaves a mark in thermodynamics again using intensive and extensive quantities (Gibbs 1876–1878). Potentials spread everywhere, from gravitational to electrical, from electrodynamic to retarded (and later to advanced), to chemical and to thermodynamic.

3 Utilizing the Energy Concept

Gibbs is also at the origin of a trend that sees energy theory influence economics. In his 1876-78 paper he formulates the criterion for thermodynamic equilibrium. Gibbs's first and probably most significant application of this approach was to the problem of chemical equilibrium. The result of his work is described by Wilhelm Ostwald as determining the form and content of chemistry for a century to come, and by Henri Le Chatelier as comparable in its importance for chemistry to that of Antoine Lavoisier (Klein 2008). Gibbs deeply influences two graduate students: the economist Irving Fisher who produces a general theory of equilibrium in the context of the neo-classical paradigm and E. B. Wilson, the developer of Gibbs' vector analysis and the mentor of Paul Samuelson. The latter applies Le Chatelier's principle to economics in 1947 and wins the Nobel Memorial Prize in 1970 (Samuelson 1970). The previous year the first of these prizes also witnesses the influence of thermodynamics on economics: the winner, Jan Tinbergen, was a pupil of Paul Ehrenfest at Leiden between 1921 and 1925 (but see: Boumans 1993). An interesting and detailed analysis of the interactions between history of energy conservation and history of neo-classical economics is given by Mirowski, who, among other aspects, outlines the correspondence between "energy" and "utility"(Mirowski 1989, De Marchi 1993).

"Energy" theories, emerging from physiology with Mayer and Helmholtz, are soon applied back to physiology by Helmholtz himself (Cahan 1993), and to psychology by Fechner, who thinks "psychophysical parallelism to be compatible with the principle of the conservation of energy" (Heidelberger 2001). Brucke, a friend and colleague of Helmholtz, plays an important role: in 1874 he asserts that "all living organisms, including humans, are essentially energy-systems to which, no less than to inanimate objects, the principle of the conservation of energy applies" (Thornton 2010). Freud studies with Brücke in Wien in the seventies and quickly adopts this new "dynamic physiology". Initially working with Breuer (Breuer & Freud 1895) he develops the idea of a "psychic energy". It is on the interpretation of this energy and of its conservation that Freud and Jung differ in the psychoanalytic domain, the former more inclined towards a mechanical view and the latter towards an energetic one. Jung in fact accepts factorization, but rejects Ostwald's substantialization. (Jung 1928 p. 20, La Forgia 1986). Jung even attempts an explanation of Mayer's achievements (Jung 1960).

Schrödinger's concept of a localized negentropy is an attempt at solving a serious dichotomy: the one between the increase of disorder (entropy) and the continuous emergence of organized structures (life) (Schrödinger 1946). His controversial contribution has an acknowledged influence on the origins of molecular biology (Perutz 1987; Fox Keller 1995). The metabolic energy balance, that is at the origin of energy conservation with the early works of Mayer and Helmholtz, only recently finds a detailed interpretation in the context of studies on the mitochondria (Brown 2000; Lane 2005).

4 Natural Philosophy Again

It is well known that Einstein in 1905 brings energy studies to a new revolutionary level, both with his quantization and with his mass-energy equivalence. It is perhaps less well-known that he made a number of attempts, eighteen between 1905 and 1946, at refining his initial derivation of the equivalence, attempts that were very interesting but basically unsuccessful. Recent literature asserts that Einstein deduced only the incremental version of the equivalence and that the famous statement "the mass of a body is a measure of its energy content" is an experimentally corroborated hypothesis but not a deduction (Fernflores 2012, par. 3.1). Possibly a derivation cannot be achieved within the special relativity framework alone (Hecht 2011). Energy conservation plays a major role in shaping General Relativity (Renn 2007).

Noether's theorem (1918) places energy conservation within the symmetry approach. The invariance for time translation is the formal result of a long search (constancy amid change) and certainly represents an achievement for the *Being* perspective.

Cassirer (1906–1907, 1910) and Meyerson (1908) offer diverging views of the philosophical history of modern science but especially of the energy principle and concept. While the title of Cassirer's (1910) (*Concept of Substance and Concept of Function*) says it all about the abandonment of "the search for an underlying ontology in favor of ever more precise mathematical representations of phenomena in terms of exactly formulated universal laws"…… "For Meyerson, by contrast …reason perpetually seeks to enforce precisely the "substantialistic" impulse, and nature continually offers her resistance in the ultimate irrationality of temporal succession…." (Friedman 2008).

Kuhn acknowledges the Neokantian influence of these debates on his own work, but surprisingly he stands with Meyerson: "Kuhn consistently gives an ontological rather than a mathematical interpretation to the question of theoretical convergence over time…For Kuhn simply assumes, in harmony with the Meyersonian viewpoint, that there is rational continuity over time only if there is also substantial identity." (Friedmann 2008). In my opinion a clear example of this is given in the famous paper on the history of energy conservation where, referring to the various conflicting formulations, Kuhn asserts: "Only in view of what happened later can we say that all these partial statements even deal with the same aspect of nature"….."We know why these elements were there: Energy *is* conserved; nature behaves that way" (Kuhn 1959).

Let's now compare Kuhn's view on energy with Feynman's equally famous one (Feynman et al.1963, vol. 2, par. 4–1, 4–4) renamed later as one of six "easy pieces": an inquiring mother realizes that the number of Dennis' blocks is always the same, despite a number of displacements. An example of "energy" conservation? Not really: "What is the analogy of this to the conservation of energy? The most remarkable aspect that must be abstracted from this picture is that *there are no blocks*."…"It is important to realize that in physics today we have no knowledge of what energy *is*. We do not have a picture that energy comes in little blobs of a definite amount. It is not that way" …."It is an abstract thing in that it does not tell us mechanisms or *reasons* for the various formulas"…. "If we had all the formulas for all kinds of energy, we could analyze how many processes should work without having to go into the details"…. "We do not understand the conservation of energy. We do not understand energy as a certain number of little blobs."…. "Unlike Dennis' blocks, there can be any amount of energy, at least as presently understood."

The debates of the last 50 years have been influenced by this paradoxical reversal of traditional roles by key players: a "divergent" physicist and a "convergent" historian (Brush and King 1972).

Becoming makes an explicit comeback in the works of the 1977 Chemistry Nobel Prize winner Ilya Prigogine. With him the debates on the irreversibility of phenomena and the arrow of time acquire new life through the thermodynamics of non-equilibrium processes. They contrast old interpretations focusing on equilibrium states and on the thermal death of the universe (Prigogine and Stengers 1979). Prigogine has also given interesting contributions to a critical history of energy theories (Prigogine and Stengers 1978).

Energy theory plays an important role in modern cosmology too. The 2011 Nobel Prize for Physics is given for the detection of the acceleration of the expansion of the universe. The expansion of a universe containing only matter should eventually slow down due to the attractive force of gravity. The acceleration of the expansion is supposed to be driven by a "dark energy" that is placed "in empty space which, according to quantum physics, is actually never completely empty. Instead, the vacuum is supposed to be a bubbling quantum soup where virtual particles of matter and antimatter pop in and out of existence and give rise to energy. However, the simplest estimation for the amount of dark energy does not correspond at all to the amount that has been measured in space, which is about 10^{120} times larger" (Nobel Prize in Physics 2011). This constitutes a gigantic and still unexplained gap between theory and observation, between cosmologists and elementary particle physicists. This makes for a good battleground for the energy conservation principle to demonstrate its heuristic capabilities.

We have gone now full (hermeneutical?) circle (Bevilacqua and Giannetto 1995). The latest cosmological research programmes present not minor philosophical similarities with the ancient Presocratic views: the concept of a "universe" as a general playground for all natural phenomena (Tales) and of two opposing tendencies that explain the *Becoming* and the *Being*: gravity and dark energy today; condensation and rarefaction (Anaximenes), cold and heat (Parmenides), love and strife (Empedocles) then.

5 Educational Concerns

Coming now to educational concerns, it is clear, even from this rapid and cursory historical recollection, that it is not easy to teach a principle which at the same time is a precondition for the scientific experience; derives from early attempts at balancing *Becoming* and *Being*, potentiality and actuality; is based on the supposition of the equality of the cause-effect relationship; on the old *ex* and *ad*; on the impossibility of perpetual motion and of its opposite; on the old distinction between intensive and extensive quantities; on the attempts at measuring all the phenomena of nature through a unique unity of measurement; on the choice of work as a stable unity; whose primary (final) expression is impossible; whose specific formulations depend on the choice of the specific theory adopted; whose forms, if independent, obey a principle of superposition; whose conservation in quantity is associated with a principle of degradation in quality; which has been derived from a time symmetry and has pervasively influenced many disciplines.

In this issue of *Science & Education*, and in a chapter to appear shortly (Bächtold and Guedj 2014), an attempt has been made to clarify some of the complicated issues connected with "Energy", its conservation and degradation. In various degrees they blend history, philosophy and education. The first two papers are more inclined towards history, the second two use history for educational purposes, the last two have a greater educational character. All of them contribute to the "nature of science" issues.

Luca Guzzardi gives a detailed analysis of Ernst Mach's antireductionist approach to energy, starting from his famous 1872 essay on "energy" conservation (whose English title conceals the original use of the term "*Arbeit*"). In an interesting and detailed comparison with Helmholtz's and Ostwald's approaches, Mach's ideas on energy and causality are also utilized to clarify some aspects of his philosophy of science.

Francesco Guerra, Matteo Leone and Nadia Robotti add to the interesting and famous case study of the prediction of the neutrino in the early nineteen-thirties, when energy conservation was questioned by some of the main players. This is achieved also through archival material related to the organization by Fermi of the first International Conference of Nuclear Physics held in Rome on October 1931. This historical account illustrates how a scientific "discovery" might develop while remaining faithful to an old theoretical paradigm, the conservation of energy, which had already proved its heuristic power in many disciplines.

Nikos Kanderakis compares some contemporary abstract definitions of the "work" concept given in textbooks for secondary and university education with its original empirical meaning. Through a discussion of the eighteenth century *vis-viva* debate and of the early contributions of French and British engineers, he shows how at the beginning of the nineteenth century the concept acquired its scientific status but progressively lost its original meaning.

Ricardo Lopes Coelho underlines the long-lasting difficulties in reaching a satisfactory understanding of the concept of energy and discusses three current educational interpretations related to energy conservation: energy as a substance, energy as the capacity for doing work and the transfer of energy. He suggests reevaluating the “empirical” content of the principle and thus adopting, instead of the energy conservation principle that in various ways follows Joule’s, Helmholtz’s and W. Thomson’s mechanical interpretations, Mayer’s principle of equivalence. Here, more than its *ex nihilo* and *ad nihilum* hypotheses, he believes that what is relevant is the “experimental” determination of the mechanical equivalent.

Rachael Lancor discusses the use of energy metaphors in science education textbooks and in the science education literature. She pays attention not just to physics but also to biology and chemistry and outlines five characteristics of energy: conservation, degradation, transformation, transfer, source. The metaphor analysis is prompted by a dissatisfaction with three traditional definitions of energy: capacity to do work, what makes “things go”, measure of change. The metaphors chosen are all “substance” metaphors, that is: “energy as a substance that can be accounted for, can flow, can be carried, can change forms, can be lost, and can be an ingredient, a product or stored in some way.” According to Lancor, taking into account the whole set of these metaphors we can offer a clearer understanding of the complex features of energy theories.

Ugo Besson and Anna De Ambrosis introduce important ecological considerations: they aim to integrate the Science Technology Society Environment approach with the conceptual and procedural dimensions of science learning. They have developed a teaching/learning path, devoted to high school students, concerning the problem of understanding the physical basis of the greenhouse effect and global warming. Special attention has been dedicated to basic energy concepts: differentiating work, heat, internal energy, temperature; considering the role of radiation in thermal phenomena; understanding energy conservation and energy balances in stationary situations of thermal non-equilibrium. Through cooperation with a group of teachers the sequence has been tested in six high school classes, with more than one hundred students.

I believe that these contributions are an interesting and original addition to the already ample and often conflicting literature on the historical, philosophical and educational aspects of “energy”.

To return briefly to the critique, cited at the outset, of our scientific and technological civilization, a critique that uses energy issues as an example (Heidegger 1953a), I wish to emphasize my deep disagreement with it. The results of this critique, “only a God can save us” (Heidegger (1966) 1976), are connected to tragic, unforgivable and unforgettable consequences (Wheeler 2013). In my view, if we have to be saved, what might save us is the continuous, strenuous, endless but enjoyable effort to understand and spread the scientific knowledge of Nature in as many aspects as possible. Energy studies are an important part of this effort and I wish to thank the authors of these six essays for their valuable contributions. I wish also to take the opportunity to thank the editor of this Journal, Michael Matthews, for his patience in the long preparation of this issue but specially for his long-lasting (25 years!) and successful efforts in promoting the worldwide professionalization of our discipline.

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