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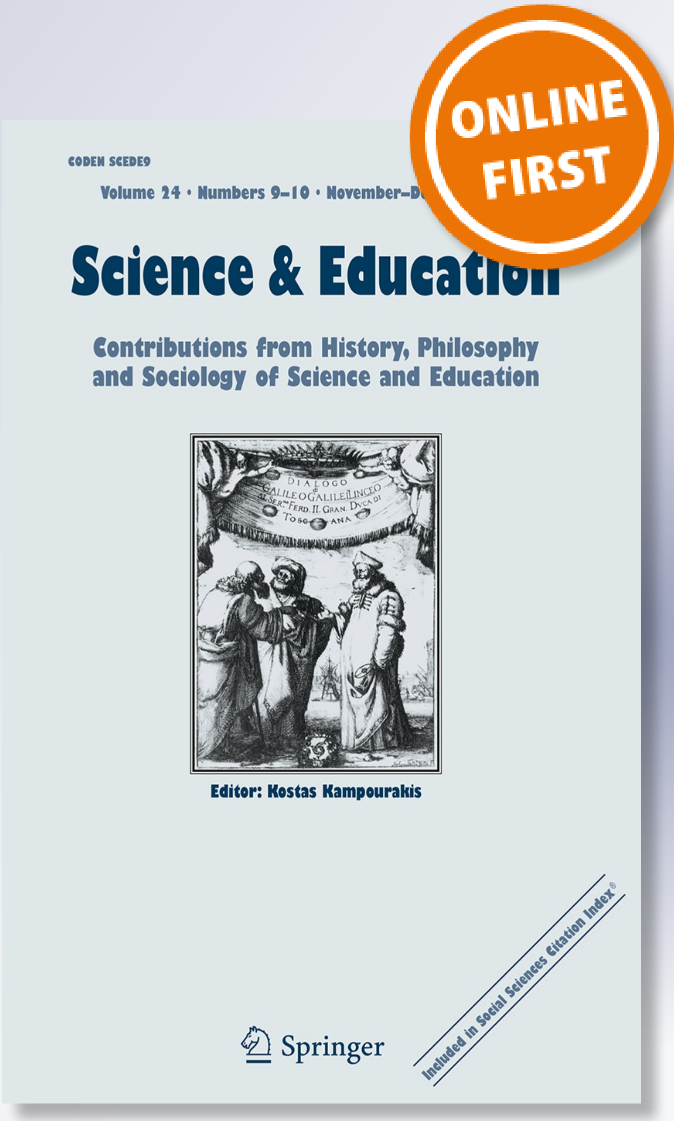

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BOOK REVIEW

Teaching and Learning of Energy in K-12 Education

Robert F. Chen, Arthrur Eisenkraft, David Fortus, Joseph Krajcik, Knut Neumann, Jeffrey Nordine and Allison Scheff (eds) (2014): Teaching and Learning of Energy in K-12 Education. Springer, Dordrecht, ISBN: 978-3-319-05016-4, 379 pp, $129 (hardback)

Dimitris Koliopoulos[1]

As mentioned by the editors of this volume, the included chapters are the product of an international energy summit held at Michigan State University in December 2013, which was aiming to get a better sense of what the research community knows about energy as a crosscutting concept and how to communicate this knowledge in kindergarten through secondary schools. Participants included scientists, science educators, science education researchers and teachers. The chapters are organized in four parts ("What should students know about energy"; "What does the research say about the teaching and learning about energy"; Challenges associated with the teaching and learning of energy"; and "Opportunities and approaches for teaching and learning about energy"). The common characteristic among these chapters is that they refer to the new Framework for K-12 Science Education, which was prepared by the NRC, and as a consequence, their mainly developmental approach is related to the teaching of the concept in the USA and the countries that are directly or indirectly influenced by this particular framework. However, this certainly does not mean that the international community would lack interest for the content of the book. When I was invited to review this book, I accepted with pleasure since I had the chance to get involved in a discussion that I personally trail for the last 30 years, since the time that my first paper was published (shared with A. Tiberghien, Emeritus Research Director at CNRS) regarding the teaching of energy as perceived from the European continental research tradition of science education.

The late 1970s and the 1980s were the golden age for energy teaching, as many innovative teaching programs appeared; they were serving the social needs of the time and going beyond the traditional, fragmented approach of teaching the concept. I could mention three exceptional, in my belief, programs that had energy as the organizational principle of the relevant syllabus: the 'Energy' program (Haber-Schaim) taught in the USA, and the European 'Libres Parcours' (Agabra et al.) and 'Neue Physik, Das

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Energiebuch' (Falk and Hermann). At the same time, worldwide we notice the appearance of many research groups in science education; these researchers evaluate the different energy teaching programs and/or place new research questions concerning the conceptual obstacles students of different ages need to overcome in order to construct a scientific understanding of the concept, if it is possible to teach the concept to young students, including the level of preschool education, and what teaching strategies are suitable so as to result in effective learning. As a representative example of the considerations of the time I could mention the series of articles from R. Driver and A. Millar introduced in the volume 'Energy Matters.'

As I was studying the book "Teaching and Learning of Energy in K-12 Education," I realized that many of the above-mentioned questions that were posed back then remain up to date. For example, several researchers continue to feel the need to respond to the arguments stated throughout Warren's emblematic article. In addition, most chapters in the book under review in order to document students' alternative notions about energy, use references deriving mainly from the 1980s. These facts manifest that the discussion regarding energy teaching, especially in the K-12 Education level, still preserves several of the elements of that time and at some point the discussion has not been efficiently renewed for over 30 years. In addition, I tend to agree with Millar's view (Chap. 11, "Towards a research-Informed Teaching Sequence for energy"), who, referring to the vast literature regarding students' conceptions and their exploitation in teaching, declares that "the ensuing debates do not seem to have led to consensus within the science education community about the goals of energy teaching. Yet without clear and generally agreed learning goals, empirical studies of teaching and learning are of limited value in advancing knowledge of how students' ideas and understanding typically develop, or for improving practice." In turn, although the problem of energy teaching seems to be stated in similar terms for years, I believe that many of the chapters in this book demonstrate intriguing aspects that may *renew* this discussion, mainly regarding to that part which leads to developmental works (new syllabuses, teaching sequences and teaching activities). At the same time, several articles raise interesting theoretical issues that I will discuss later on. One way or another, for example, many issues have been (re)addressed, such as a) the definition of energy in various educational levels, b) students' (or/and teachers') conceptual difficulties during the construction of a scientific version of the energy concept, c) the numerous forms that the model of storage–transfer–transformation of energy can take, as a suitable didactical transposition, especially for the lower educational levels (a great number of chapters of this book refer to this conceptual approach) and, finally, d) the potentiality of designing appropriate cross-, inter- and/or transdisciplinary teaching sequences that are based on energy.

With regard to the development of teaching proposals, a cluster of articles describe or outline, more or less, innovative teaching sequences or teaching activities, as well as innovative seminars for teachers' training. Millar (Chap. 11, "Towards a research-Informed Teaching Sequence for energy") suggests a complete teaching sequence of physics for students up to 16 years old. Vigeant, Prince and Nottis (Chapt. 13, "Repairing engineering students' misconceptions about energy and thermodynamics") and Wendell (Chap. 15, "Opportunities for reasoning about energy within elementary school engineering experiences") suggest series of teaching activities related to the engineering curriculum, whereas Lacy, Tobin, Wiser and Crissman (Chap. 14, "Looking through the energy lens: A proposal learning progression for energy in grades 3–5"), Stacy, Chang, Coonrod and Claesgens (Chap. 16, "Launching the space shuttle by making water: the chemist's view of energy") and Cooper, Klymkowsky and Becker (Chap. 17, "Energy in chemical systems:

An integrated approach") suggest teaching sequences and/or teaching activities related to the chemistry curriculum. Finally, Seeley, Vokos and Minstrell (Chap. 19, "Constructing a sustainable foundation for thinking and learning about energy in the twenty-first century") use interesting innovative activities to train teachers in issues of energy teaching. One of these activities is based on drama ("Energy theater"), a method that has been commonly used and proved effective in science teaching for lower educational grades.

On the research level, we find interesting theoretical and methodological approaches. The considerations of many chapters orbit around the concept of "integrated understanding of the energy concept," which nonetheless constitutes the basic organization principle for the goals and the content of the energy summit that led to the publication of this book (Chap. 1, "Introduction: Why focus on energy instruction" and Chap. 20, "Conclusion and Summary Comments: teaching energy and associated research efforts"). This concept has many meanings and can take different forms; the common element between these forms is to explore whether students can create conceptual connections in different levels and contexts of argumentation about the concept of energy. Some of the forms that this concept can take are the following:

a. The *differentiation* and finally the *integration* in a common conceptual frame of energy concepts that pupils and university students are not able at first to differentiate when using everyday life ideas for energy. Tracing energy separately from matter for analyzing carbon-transforming processes (Chap. 3, Lopez, "A space physicist's perspective on energy transformations and some implications for teaching about energy conservation at all levels") and attempting to differentiate the concepts "energy" and "entropy" through a proper energy metaphor (Chap. 18, Wei, Reed, Hu and Xu, "Energy spreading or disorder? Understanding entropy from the perspective of energy") are characteristic examples of this form of integrating the understanding of energy.
b. The effective *association* of energy explanations of phenomena that belong to different conceptual frames and are expressed in different language and terminology (e.g., association of macroscopic and microscopic conceptual energy models). Dauer, Miller and Anderson (Chap. 4, "Conservation of energy: An analytical tool for student accounts of carbon-transforming processes") focus on biological systems at multiple scales, from carbon-transforming processes described at the atomic/molecular scale to energy flow through ecosystems and global environmental systems, and they develop and apply a learning progression on energy in complex biological systems using quasi-quantitative representations of energy in both macroscopic and microscopic level. Also Cooper, Klymkowsky and Becker (Chap. 17, "Energy in chemical systems: An integrated approach") consider as a necessity for students the creation of associations between macroscopic, atomic/molecular and quantum mechanics energy explanations of the phenomena, if they want to thoroughly understand chemical phenomena and bond formation concept.
c. *Integrating* different levels of energy concept formulation (e.g., qualitative/semiquantitative and quantitative energy approaches). The need to introducing qualitative elements in energy teaching appears in many articles, in order to either justify the notion that energy should be taught in lower educational grades (Chap. 14, Lacy, Tobin, Wiser and Crissman, "Looking through the energy lens: A proposed learning progression for energy in grades 3–5") or support the view that even in higher educational levels students cannot obtain coordinated knowledge about energy merely through mathematical formulas, but they have to give a meaning to the equations by

constructing in parallel an energy model based on qualitative explanation. Duit (Chap. 5, "Teaching and learning the physics energy concept") brings back the well-known idea for teaching energy as a substance-like quantity, clarifying to the opponents of this idea that "to view energy *as if* it were a certain kind of substance may help students to understand energy." Wei, Reed, Hu and Xu (Chap. 18, "Energy spreading or disorder? Understanding entropy from the perspective of energy") describe a systematic qualitative approach of the spontaneous physical or chemical phenomena and their explanation in the context of teaching the second thermodynamic law. In the context of this approach, they use two remarkable, in my belief, metaphors (the "energy dispersal metaphor" in the macroscopic level and the "entropy metaphor" in the microscopic level) as intermediate qualitative representations scaffolding the capture of mathematical forms of the second thermodynamic law.

d. The *possibility of creating* common phenomenological fields in order to discuss the energy concept (e.g., common fields of physical, chemical, biological or geological phenomena and/or engineering experiences). This, even though it appears in many chapters, it is expressed more as a wish and less as scientific data. In regard to this particular form, we could distinguish the epistemological aspect and the learning aspect. The epistemological aspect is concentrated in the question "is always possible the creation of common phenomenological fields that are explained by an energy model"? or, in a different way, "are there phenomenological fields that are particularly privileged to be explained by an energy model"? For students of different educational levels, the learning aspect refers to the potentiality to construct significantly abstract forms of explanation, such as the law of the conservation of energy in its most unifying versions (e.g., the Feynman version for all phenomena or the version of the first thermodynamic law for different thermodynamic systems). Quinn (Chap. 2, "A physicist's musings on teaching about energy") places the matter of science teaching in the context of a unified energy explanation for all the phenomena in the microscopic level ("The unifying ideas and technical definitions [about energy] are all at the atomic or sub-atomic level"). But again, the epistemological question returns in another form: "Is it possible for the energy concept to maintain the same meaning in different theories (e.g., classical mechanics, macroscopic thermodynamics, quantum mechanics)"? And if not, as several researchers suggest, then is a unified teaching of energy really possible? Or could it be that the real wealth of energy teaching lies exactly in the different meaning that the concept preserves in every conceptual frame inside of which it functions?

e. *Integration* of cultural elements in energy teaching (e.g., introduction and integration of history and philosophy of science, environmental problems and/or matters of everyday life to teaching). Jin and Wei (Chap. 9, "Using ideas from history of science and linguistics to develop learning progression for energy in socio-ecological systems") and Papadouris and Constantinou (Chap. 12, "Distinctive features and underlying rationale of a philosophically—informed approach for energy teaching") connect energy teaching to the research field that most commonly appears by the name history, philosophy, and science teaching" (abbreviation HPST). The discussion whether such a correlation is useful in science teaching or, on the contrary, creates confusion and complications, lasts for decades. But still it is worthy, in my opinion, to further investigate the issue of teaching energy from the point of view of this research field, because many of the questions could be approached by a non-empirical way and many teaching proposals can be interpreted by an epistemological valid way. The reader may find interesting approaches on this matter in articles of this journal.

Additionally, Liu and Park (Chap. 10, "Contextual dimensions of the energy concept and implications for energy teaching and learning") point out at large the role of the cultural contexts in student understanding of the concept of energy. More specifically, they suggest that energy teaching should be approached not only as a distinctive scientific concept, but also as a "scientific world view," as a "cultural construct" and as "civic literacy."

In respect to the research methodology, this book includes two interesting approaches of content analysis of large-scale curricula. L. Wang, W. Wang and Wei (Chap. 6, "What knowledge and ability should high school students have for understanding energy in chemical reactions? An analysis of chemical curriculum standards in seven countries and regions") conduct a qualitative analysis of the conceptual requirements of seven international energy teaching programs, while Chen, Scheff, Fields, Pelletier and Faux (Chap. 8, "Mapping energy in the Boston public schools curriculum") guide teachers to construct a network of units concerning the energy concept, which are contained in the Boston Public School Curriculum, using graph theoretic technics. Even though the research may have a local interest and relate merely to a local teaching community, the applied analysis technique seems interesting.

In conclusion, I believe that this collective work makes a significant contribution to further enrichment of the already massive bibliography concerning the issue of energy teaching and the systematic investigation of the epistemological, learning and teaching dimensions. In the final chapter of the book, the editors recommend future research directions, many of which have already been launched since decades. I would like to wish the readers of the book to have a pleasant reading, while waiting for the next milestone of this Sisyphean effort conducted by the international educational community regarding the teaching and learning of energy.

Compliance with Ethical Standards

Conflict of interest The author declares no conflict of interest.