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ARTICLE

Teaching About Energy

Application of the Conceptual Profile Theory to Overcome the Encapsulation of School Science Knowledge

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Abstract
In this article, we draw upon the Conceptual Profile Theory to discuss the negotiation of meanings related to the energy concept in an 11th grade physics classroom. This theory is based on the heterogeneity of verbal thinking, that is, on the idea that any individual or society does not represent concepts in a single way. According to this perspective, the processes of conceptualization consist of the use of a repertoire of different socially stabilized signifiers, adjusted to the context in which they occur. We start by proposing zones of a conceptual profile model for energy, each zone being characterized by its own commitments and identifiable by certain modes of talking about energy. Based on classroom evidence, we claim that teachers and students negotiate meanings that interpenetrate the domains of everyday and scientific knowledge. Being inevitable and necessary, this heterogeneity of conceptual thinking needs to be considered in teaching design in order to allow its awareness on the part of the students. We argue that students' conceptual development goals should be considered in terms of general goals of science education, which points to the need of overcoming the encapsulation of scientific school knowledge. We show that the Conceptual Profile Theory provides a basis for science education that can promote the crossing of cultural boundaries, seeking relations between science and the spheres of everyday life.

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1 Introduction

The importance of the concept of energy in science is undeniable, whether due to its scientific and academic relevance, to its social, environmental and technological applications, or to its implications for personal and collective decision making in contemporary society (Chen et al. 2014). Although introduced in the history of science just in the second half of the nineteenth century, energy is a core scientific concept. In physics, the principles of conservation (energy, linear, and angular momentum) make up, together with the concepts of mass, space, and time, the fundamental pillars for understanding the physical world at all scales, from subatomic processes to the whole universe, and with regard to its constitution, origins, and evolution. Energy appears as a property of systems, an amount that manifests itself in different forms and is associated with different processes, being conserved and degraded in transformations and transfer. Having its origin in physics, energy is a crosscutting concept, integrating different fields of scientific investigation (NRC 2012). According to Bunge (2000, p. 458), "all the sciences that study concrete or material things, from physics to biology to social science, use one or more concepts of energy."

In the sphere of social life, the concept of energy is also remarkably present. There are many themes of contemporary life in which this concept is central and for which decision making on personal and collective levels demands some understanding about energy. Among them, the following stand out: different ways of obtaining energy, search for energy efficiency, cycles of matter and energy in ecosystems and sustainability problems, health issues involving diets and physical activities, ways of obtaining and regulating energy in living beings, and energy obtained in chemical and nuclear processes, among many others. These issues, in turn, refer to debates on the relations between science, technology, society, and environment, of undeniable importance for science education (Liu and Park 2014).

In spite of this relevance, there are several major challenges in the teaching of energy. According to Millar (2014), these problems derive from three complementary sources. First, energy is an abstract idea, difficult to express in simple language; second, there are huge differences between the modes of conceptualization[1] of energy in everyday life and in science; and third, the energy concept is used with different emphases and different languages and conceptual frameworks in the various disciplinary fields. Thus, it is no wonder that the teaching of energy has been a topic of specific conferences in science education, such as a well-known conference held in Leeds, UK, in 1985, and a more recent one, at the University of Michigan, in 2013. In both cases, the conferences resulted in books including comprehensive studies on the theme (Chen et al. 2014; Driver and Millar 1986). Despite all these efforts, the learning and teaching energy continues to demand new studies and approaches.

Research carried out in the 1980s offered a detailed analysis of students' ideas about energy and found remarkable differences between the analyzed modes of conceptualization and foundational ideas in the scientific concept of energy (Bliss and Ogborn 1985; Duit 1984; Trumper 1990; Watts 1983). Among the contributions of more recent research, there have been three main types of research: (1) trials of an integrated treatment of energy in different domains of human knowledge (Dauer et al. 2014; Jewett Jr 2008); (2) proposals of outcomes, in terms

[1] By mode of conceptualization we are referring to the different status of concepts in the domain of everyday life knowledge and scientific knowledge. In science, concepts are theoretical units that are part of a structure of knowledge that is focus of a deliberate analysis. In the realm of everyday life, concepts are much more elusive, flexible, and oriented to practical action.

of learning progressions about energy throughout the curriculum (Jin and Anderson 2012; Lacy et al. 2014; Neumann et al. 2013); and (3) didactic approaches using different modes of representation of the concept, with greater attention to the relations between language and cognition (Ametller and Pintó 2002; Lancor 2014; Seeley et al. 2014; Wei et al. 2014). However, it remains a challenge how to integrate the school treatment of energy ideas with knowledge that can be useful and meaningful for students to cope with contemporary problems involving energy, the environment, and society.

The differences between the modes of conceptualization in science and in everyday life have been emphasized by many authors. Solomon (1992) referred to two domains of knowledge, with differentiated epistemological commitments. The first domain, based on the general stock of knowledge and common-sense operations, is driven by pragmatic value and greater conceptual flexibility. The second, the scientific domain,[2] refers to the world of theoretical entities, orchestrated in order to compose a structured, rational, and abstract view of the world in which we live.

In science, energy is an abstract quantity, not directly observable, which manifests itself in different ways and can be converted into other types while keeping, in isolated systems, the same original quantity. It can also be transferred from one system to another (or between parts of the same system), and its quantity can be accounted into a kind of balance sheet. Although conserved, the system's ability to produce transformations is reduced over time as part of the energy inevitably degrades into heat and cannot be reused.

In the everyday realm, energy is understood as a kind of fuel and is, in this sense, essentially non-conservative: we pay for energy, we use it and, after a certain time, it comes to an end. Energy appears as the quality of energetic things and manifests itself in obvious activities, such as fire and movement. It is also conceived as a quality of living beings and as an ability to act or to be active.

In the conceptual change model for learning (Posner et al. 1982), students' ideas at odds with the scientific perspective are treated as an obstacle to overcome and instruction is designed to address the replacement of these ideas (typically supposed to be naïve) by the scientific concept. In opposition to this assumption, we consider that it is both impossible and undesirable to banish the general stock of knowledge that students bring from their social life. As Solomon stated,

> Old ideas simply cannot die out and be replaced if they are perpetuated through daily talk; and indeed it would be a poor return for a short school course on energy if pupils found themselves unable to understand its life world meanings. If our pupils are to continue talking sensibly about energy with friends and family they will have two quite different sets of ideas about energy co-existing in their minds. (Solomon 1992, p. 103)

We argue that it is necessary to add three aspects to the model of two domains of knowledge proposed by Solomon (1992). First, everyday thinking is not monolithic. On the contrary, research results indicate a plurality of ideas and commitments that inform the views on energy in everyday life. Thus, considering students' views on energy involve examining in more detail what these commitments would be, and how they are anchored in ways of thinking and talking about energy in the various contexts of social life. Secondly, the same can be said about

[2] Contrary to Solomon, we recognize that there is more than a single domain of science. There is much polysemy in the scientific interpretations of energy, and some of these interpretations are nearly exclusive to specific scientific subdomains, e.g., physics, chemistry, geology, ecology, and molecular biology. We address this later in the article.

the scientific domain; there are controversies about the scientific meaning of energy and they are related to advances in scientific knowledge itself. In physics, for example, advances in cosmology and astrophysics, as well in quantum mechanics, raise new approaches and queries related to the energy concept (for example, cosmic radiation and dark energy). Thirdly, it must be recognized that these two domains of knowledge, although distinct, influence each other. On the one hand, the ways of speaking and thinking about energy in everyday life are, in some way, influenced by the discourses of science and technology. On the other hand, science recurrently uses intuitions, modes of metaphorical and analogical reasoning, to compose and communicate systems of knowledge. From the pedagogical point of view, this affords the possibility of establishing bridges among conceptualizations of energy in everyday and scientific domains. Our advancements are substantiated, in part, by work of Scherr and Robertson (2015) and others, who have demonstrated that canonically incorrect ideas can be productive in certain contexts depending on specific instructional goals, culture of collaborative meaning-making, and certain representations about energy. These authors consider that an idea is productive whenever it constitutes valuable material that learners can use to make intellectual progress, enriching their conceptual repertoire.

According to Lijnse (1990), the question is *whether* there are bridges between these two domains of knowledge and then the problem unfolds in two others: "Does a theoretical understanding of energy also have a direct significance for coping with energy in one's life-world? Or, vice versa, does one's life-world experiences with energy constitute a useful starting point for developing one's theoretical understanding of energy?" (Lijnse 1990, p. 579). According to this author, science, technology, and society (STS) approaches advocate a positive answer to the first question, pointing to a perspective of more relevant science teaching, while a favorable answer to the second question is given by constructivist perspectives. Both answers, however, deserve further analysis.

In this article, we present a preliminary version of a conceptual profile model of energy, used to identify the meanings that emerged and are negotiated in a physics class in an urban school in the USA. We chose this context because of its diversity of students who come from many countries and cultures of the world, and whose families span a very wide socioeconomic range. In this way, we hoped to observe a large variety of conceptual modes of energy. For this, we start by justifying the choice of the Conceptual Profile Theory to perform such analysis and inform contributions to the debates on teaching about energy. Next, we present a preliminary proposal for the zones of a conceptual profile model of energy, based on the literature on students' understanding of energy and on the historical development of the concept. We then follow the teacher's actions in introducing the concept of energy in mechanics. The following questions guided our observations and data analysis:

- How does the teacher introduce aspects of scientific knowledge in her classes?
- How does the heterogeneity of ways of speaking and thinking about energy manifest itself in the statements of the teacher and students in a physics classroom?
- How does the teacher create (or how could she create) opportunities for the students to become aware of their own conceptual profiles of energy?

In this, we maintain a commitment common to our prior work (Scott et al. 2006; Szteinberg et al. 2014) to studying the practices of outstanding science teachers, because this provides a window for others into the possibilities that are accessible with excellent teaching. Thus, this research aims to help teachers become aware of the elements that make up the conceptual energy profile in order to better design teaching strategies and approaches (Aguiar 2014).

2 The Teaching of Energy and the Conceptual Profile Theory

The idea of conceptual profile was proposed by Mortimer as an alternative to Posner and colleagues' conceptual change model (Mortimer 1995; Posner et al. 1982). Like other authors in the 1990s (Caravita and Halldén 1994; Linder 1993), he contested the then-prevailing hypothesis that learning scientific concepts called for the abandonment of common-sense ideas and beliefs that were in disagreement with the scientific perspective. This proposal has recently been expanded to encompass sociocultural approaches to development and learning and to objective pragmatism as an epistemological basis (Mortimer et al. 2012; Mortimer and El-Hani 2014).

Rather than conceiving of learning as just a rational choice between different alternatives, the conceptual profile theory considers that many major concepts in science exhibit a heterogeneity of forms of thought that may have pragmatic value in appropriate contexts. Thus, learning science does not correspond to deconstructing non-scientific knowledge since we pragmatically use different systems of knowledge in the various instances of social life. Instead, the conceptual profile theory proposes framing the problem of generating new meanings in science by considering the interplay of different modes of thinking and ways of speaking:

> In the conceptual profile theory, conceptual learning is conceived as consisting of two interwoven processes: the construction of new ways of thinking and modes of speaking—new zones of a conceptual profile—and the dialogue between new and old zones, with a keen focus on the need that students become aware of the very diversity of modes of thinking and the demarcation between their pragmatic value in distinct contexts. (Mortimer and El-Hani 2014, p. 12)

Therefore, the conceptual profile theory entails an approach to teaching and learning scientific concepts that considers the existence of different ways of conceptualizing the world that are used by individuals to signify their experiences. These different forms of understanding a concept are materialized in culture in relatively stable zones of meaning-making, which are related to specific ways of thinking and speaking. We use these zones to understand and act in specific situations. Each zone of the profile corresponds to a way of thinking grounded in specific epistemological commitments (criteria from which knowledge is produced and validated), ontological commitments (beliefs about the nature of the objects of knowledge), and axiological commitments (values and purposes associated with knowledge and beliefs).

The conceptual profile theory states that, for each concept in a given culture, there are different ways of thinking that constitute relatively stabilized zones of meaning that in turn compose repertoires used by individuals of this culture when using that concept in a diversity of situations. Thus, conceptual profile models can be built for a given concept (e.g., energy), considering a spectrum of meanings ascribed to that concept in its broad cultural significance, whether in the domain of general knowledge, used in everyday life, in the scientific domain, in the school science domain, or even in more specific communities of practice.

For example, a study conducted by Araujo (2014) examined the uses and understandings of the concept of heat by refrigeration technicians and brigade firefighters in their practices and professional training courses. For these communities, particularities were registered, such as the use of the concepts of "thermal load" or the "fire tetrahedron" by firefighters, and the recurrent use of heat associated with temperature, thermal sensation, and substance by subjects of both communities. Even though they knew the scientific concept, these professionals used different meanings for heat, considering their pragmatic value in dealing with problems in the specific contexts where they worked.

Another study was conducted by Hewson and Hamlyn (1984) with members of a Sotho community group in a remote area in South Africa. Anthropological studies report that members of this community use a metaphor according to which "coolness is good" (implying health and social harmony) and "hot is bad" (implying sickness and social disharmony). These metaphors are grounded in the hardship caused by a hot, dry environment, which influenced their language and cultural beliefs. In the study by Hewson and Hamlyn, interviews were conducted with school-aged community members (15 years old and older) and adults with basic schooling, with protocols exploring situations that elicit the metaphorical conceptions of heat and, also, conventional physical situations to be analyzed. A result of the study was that several members of the community used the metaphorical conceptions of heat and cold in certain contexts, but were also able to interpret phenomena using physical models. Most strikingly, physical phenomena were interpreted by most subjects on the basis of mechanical models of matter, with only two records (in 20 subjects interviewed) of substantialist conceptions of energy. The hypothesis of the authors is that the metaphors of heat used by the community approached a conception of heat as movement, not as matter.

We chose to approach the problems of teaching energy through the conceptual profile theory for two main reasons. First, this theory is based on a solid sociocultural framework which considers conceptualization as an emergent process always produced through the interaction between an individual and some external event or experience (Mortimer and El-Hani 2014; see also Vygotsky 1987; Wertsch 1985). From this perspective, it is important to distinguish concepts, as social constructs that result from culturally stabilized meanings, and the processes of conceptualization that take place when subjects are engaged of meaning-making and communication that must be analyzed in the contexts in which they are realized. In these terms, scientific concepts do not reside in the minds of scientists and experts, but in a set of language artifacts and worldviews that stabilize in practices and reference values for groups or individuals who engage in concrete meaning-making acts (Wells 2008). The heterogeneity of conceptual thinking is a consequence of the different spheres of social life. Scientific concepts are an important part, but do not exhaust all the forms of conceptualization produced in and by human experience, and used with pragmatic values in the spheres of social life.

Second, the conceptual profile theory seeks to put in dialog scientific and non-scientific perspectives on the use of concepts in social life, thus breaking with the encapsulation of scientific school knowledge (Engeström 1991). In doing so, it does not succumb to relativisms that dilute the differences between scientific and everyday knowledge (El-Hani et al. 2014). While recognizing the pragmatic value of various non-scientific concepts in their spheres of use, the conceptual profile theory insists that these different modes of conceptualization have different values that must be considered in their own contexts of use. Thus, the value of science and scientific knowledge is affirmed in the contexts of the practices and purposes of this way of representing, conceiving, and acting upon the world. The concept of energy, for example, as an abstract quantity that is preserved in transformations, is affirmed as a powerful instrument for understanding natural processes and for dealing with new technologies. It must, however, be in dialog with other discourses in daily life that interpret conserving energy as keeping, saving, or preserving it for better use. If we want science education committed to life and society, energy discourses in school cannot be isolated from their social uses.

The Conceptual Profile Theory demands a meta-reflection on the concepts we use and the ways we use them in different spheres of social life. Thus, it is a theory that supports us to understand the interplay between different ways of thinking and modes of speaking in actual science classrooms.

3 A Proposal for the Conceptual Profile of Energy

Based on historical studies on the concept of energy (Coopersmith 2015; Elkana 1974; Smith 1998) and a literature review on the characteristics of both everyday and scientific thinking about energy, we propose a conceptual profile model of energy, naturally subject to modifications, in order to build an analytical framework for understanding processes of meaning negotiation about energy in science classrooms. This proposition is based on a recent study (Simões Neto 2016), which developed a model of a conceptual profile of energy restricted to the context of chemistry and physics teaching. The modifications we have made on Simões' proposal are justified, in part, by the importance we give to the biological context in both the historical and the conceptual development of the energy concept.

Following the historical development of the scientific concept of energy, we find not an inert and steady concept, but a vivid and transforming one. As Elkana noted, we can say that

> It must be made clear that scientific concepts do not emerge in a logical, clear-cut-for-the-need form; that whatever the final formulation of a physical law, the concept that emerges of this formulation is not identical with the concepts in which the discoverer of that law was working while his discovery was being crystalized; any such attempt of identification is pure hindsight. (Elkana 1974, p. 58)

Elkana claimed that the factors that led to the proposition of the Energy Conservation Principle involved an interpolation between physics and philosophy, given the a priori general belief in the conservation of causes ("forces") in nature, which was the core idea behind the work of Joule, Meyer, Faraday, and Helmoltz. Elkana also mentioned the influence of studies on animal heat and the discussion of "vital forces," in terms of processes irreducible to the laws of inanimate matter, a view that was to be replaced by the energy approach. In turn, Smith (1998) argued that a nineteenth-century history of the concept of energy cannot make sense if treated only as an internal history of physics, with no place for cultural, economic, religious, and philosophical issues of its time. One of the facets of the concept of energy is linked to theories of the driving power of heat and thermal machines involving both engineers and practical workers as well as experimental and theoretical scientists.

In the description of each of the zones of the profile, we will also refer to studies about energy in science education, especially in the tradition of research on students' alternative conceptions. We interpret these conceptions as stemming from modes of thinking that have their origin in social life (Mortimer et al. 2012; Solomon 1987) and, thus, appear as flexible and dynamic structures (Berger and Luckmann 1967; Guidoni 1985). Culturally stabilized, they allow communication between different subjects in contracts of intersubjectivity (Mortimer and Wertsch 2003). As we will see, these different ways of thinking and talking about energy overlap in individuals' utterances in specific contexts of communication. We can understand this hybridization of statements as arising from the pragmatic use of concepts in particular contexts, which is often operated unconsciously and unintentionally (Crepalde and Aguiar Jr 2018). In the literature on alternative conceptions of energy, there is a profusion of classifications of frameworks underlying the ways of thinking and speaking of children and adolescents about the concept of energy (Louisa et al. 1989; Trumper 1990; Watts 1983). These classifications do not coincide with each other and the boundaries between them are not very clear. We attribute these differences and difficulties to the fact that, in concrete statements, we have a superposition of modes of thinking.

In defining the zones of a concept, we follow two basic criteria. First, we avoid proposing an excessive number of profile zones, which would make them difficult to use for teaching purposes. Secondly, we seek to identify the zones by the underlying epistemological and ontological commitments. The profile proposed here is composed of six zones, shown in Table 1, and described in detail below. The last zone will not be discussed in this article because it is absent in the teaching approach that we observed.

By epistemological, ontological, and axiological commitments, we refer to implicit beliefs that support a given way of signifying a concept. For example, we recognize an epistemological commitment related to empiricism when a student talks about energy by evoking an observable event that denotes the presence of energy (moving water, for example), but its presence is absent in other situations in which no such observables manifest (such as water dammed in a hydroelectric plant). Thus, for this student, energy is an activity; if there is no activity, there is no energy. This does not mean that this student, when using this idea of energy, is aware of its underlying commitment, nor that this commitment is so strong as to guide his interpretation of the concept in other contexts. Even though the epistemological and ontological commitments are not recognized by the individual, neither explicitly nor systematically, to the point of guiding the subject's behavior in other contexts, they provide the basic criteria for delimiting the zones of meaning of a given concept in a given culture. We are not, thus, ascribing to the students the sophisticated, explicit, and systematized epistemological perspectives denoted in the philosophical literature by terms such as "rationalism" and "empiricism."

Table 1 A conceptual profile model for energy

Zones	Description	Commitments
Z1. Vitalist zone: energy as a vital quality	Energy as a quality of life, as something that living beings use to be active; energy as being energetic	Essentialism Anthropomorphism Sensualism
Z2. Empiricist zone: energy as a (functional) activity	Energy as movement, transformation and vividly experienced things, especially those functional for some practical purpose	Empiricism Finalism
Z3. Substantialist zone: energy as a quasi-material thing	Energy as a material or quasi-material entity that can be stored in objects, transferred from place to place and spread out	Substantialism
Z4. Causal zone: energy as a causal agent	Energy as the cause of events; a power of making things happen	Rationalism Effective causality
Z5. Scientific classical zone: energy as a quantity that is conserved and degrades	Energy as subject to conservation, degradation, transformation and transfer	Rationalism (classic) Formal causality
Z6. Quantum rationalist zone: energy as a discrete quantity, related to wave function, probability, and rest mass	$E = mc^2$, $E = hf$, $E\psi = h\ \delta\psi/\delta t$	Rationalism (modern)

In another research (Aguiar et al. 2019), conducted at a different public school of the same urban school district, we followed a science teacher in the development of a sequence of teaching about energetics in chemical reactions with eighth-grade classes. At the end of the sequence, we interviewed five students who participated in this study. The purpose of the interviews was to identify the meanings attributed by students to the concept of energy in the context of the study of chemical reactions (whose protocol we do not present here) and in other contexts (protocol described below). In this article, we extracted typical student statements in the interviews only to exemplify the proposed profile zones.[3] The participants were presented with eight cards with the following words and a simple color drawing of each: a growing tree, a dead tree, a running mouse, a dead mouse, a sleeping boy, a burning candle, a boy in the snow, and a boy pole vaulting. Each participant was asked to respond to the following two questions: (1) Is there any energy in the system represented? Explain the reasons for your choice. (2) If yes, where does the energy come from, and how is (or can) this energy be used, transferred, or transformed? The interviews were transcribed, and four researchers (the authors and one graduate student) separately coded the students' statements to look for the presence of the proposed zones of the energy conceptual profile. Upon tagging an utterance with a zone, the researchers provided metadata to explain why they assigned this zone. The first author then analyzed these results, choosing examples for each zone to be presented in Table 2 in common agreement regarding the categorization with all authors. As can be seen in Table 2, several of these statements express commitments and ways of speaking of more than one area of the profile, indicated by graphic markers (bold, italic, and underlined). The primary zone in each quote is marked in bold face, and the explanation of the hybridization with the other zones is given next to each example.

Figure 1 provides a graphical representation of the overlapping of the zones related to everyday meanings of energy.[4] For example, ideas of power can be related to different zones: "energy is the power of life" (Z1 vitalist zone); "energy gives power to make things easier" (Z2 empiricist zone); "energy is the power of fuels" (Z3 substantialist zone); and "energy is force, strength and power" (Z4 causal zone). In this representation we also connect basic ideas of the scientific zone (Z5 scientific classical zone) to other ideas from the non-scientific zones. As we argue later, these non-scientific ideas can be productively used to bridge the gap between them and the scientific ideas. We anticipate that these connections transform meanings from both sides and do not represent a single correspondence.

3.1 Zone 1: Energy as a Vital Principle—the Vitalist Zone

In studies carried out by Watt (1983), several "reasoning structures" have been identified that support spontaneous energy thinking. For instance, it is possible to identify an anthropocentric or anthropomorphic way of thinking that leads one to conceive of energy as something inherent to living beings. According to Watt, young children often link energy to growth, physical activity, and nutrition. According to Driver et al. (1994), energy in this sense is something that is felt and perceived, with reference to personal experience. However, we must be cautious when relating utterances that connect energy to life or living beings to an expression of vitalist conceptions of energy, without any epistemological and ontological

[3] The methodological grounds for the proposal of the zones of the conceptual profile of energy extrapolate the objectives of this paper.

[4] To elaborate this representation, we were inspired by Solomon's (1992) mapping of energy themes. However, Solomon presents a mapping of contexts, not of concepts. She also does not establish relations between the spheres of general knowledge and scientific knowledge.

Table 2 Examples of students' utterances and their analysis using the energy conceptual profile model

Zones	Examples from the interview with codes	Explanation of fit of code(s) and hybridization
Z1. Vitalist zone: energy as a vital quality	Interviewer: The dead tree has energy? Student 1: I do not think so, **because it's not growing anymore. I think like what a dead tree, that's like what it is.** It cannot, um, it's **like cells are not anymore and they are all dead**, *so they cannot do anything. They cannot get the nutrients from the soil anymore, because they need like working cells or something* [?] roots and stuff. **They are all dead,** ***so they cannot do what they need to do.*** (**Z1** + *Z2*)	This is **Z1** due to the identification of energy with life and its general properties (growth and nutrition). This is *Z2* due to the idea of energy as a functional thing: the dead has no energy, so it cannot do anything.
Z2. Empiricist zone: energy as a (functional) activity	Student 2: Um, I think **<u>energy conservation, it's also kind of like what you do in normal life, how when you are running, you do not want to go like too fast, or um so that you do not have energy at the end</u>**. You want to conserve it. So I think that means that um, ***bonds, atoms and molecules, they have energy inside them, because they are always moving. So they are never not moving or moving too quickly.*** (**Z2** + <u>Z3</u> + *Z5*)	This is **Z2** due to the identification of energy and movement and also <u>Z3</u> due to the idea of conserving energy as keeping it inside, not using or saving it. The second sentence exhibits commitments with **Z2** and *Z5*, due to the attribution of energy to submicroscopic entities (bonds, atoms and molecules) and a conclusion: if they have energy, they are always moving.
Z3. Substantialist zone: energy as a quasi-material thing	Student 3: But I think like **the calories, you kind of like store up, and then you can like use them all, like over time**, I guess. Like **when you burn them off, you are using a lot of energy**, so like you can like **burn them off over time**, and that's *kind of our bodies' way of like telling us that like we are burning off energy*, and like how **much energy we have left to burn, pretty much**. (**Z3** + *Z1*)	This is **Z3** due to the idea of energy as a quasi-material substance which can be stored up or burned off. This is *Z1* (in a light form) due to the identification of energy as a kind of fuel to life.
Z4. Causal zone: energy as a causal agent	Student 1: We use energy in a lot of different contexts. It's just like a sort of **like force to kind of think of it as that can be used to do a lot of things**, like whether it's ***keep a tree alive or give something heat and stuff***, it's just like, it's *a sort of thing that's there in everything*, and it, I do not know, **kind of makes things, gives things.** (**Z4** + *Z1*)	This is **Z4** due to the idea of energy as a force, a power of doing things, making things or giving things. This is *Z1* due to the idea of energy as a source of life, in a broader sense.
Z5. Scientific classical zone: energy as a quantity that is conserved and degrades	Interviewer: All right, so like what does it mean to you to say that energy is conserved? Student 1: I think it means that **no matter what happens to the energy in like its surroundings and stuff, that energy, it just cannot disappear**. *It has to stay there*, **whether it becomes in a different form or it is used in different ways** *to reaction to something*. The *energy is still there in some like shape or form*. (**Z5** + *Z3*)	This is **Z5** due to the commitment with the general idea of energy as a quantity that conserve itself during transformations. This is *Z2* due to the material attributes of energy.

In Table 2, selected segments of the utterances identified with specific energy zones were written in **bold**, *italic*, or <u>underline</u>, corresponding to the typographical emphasis used to nominate the respective zones, in each case (in the first example, segments codified as **Z1** are marked in **bold** and segments codified as *Z2*, in *italic*).

commitments that clearly characterize this zone. That is, in some cases the utterance is an expression of other components of the profile.

In the vitalist sense, energy is a property of objects, or a state of being, or being "energetic," willing, active, and vigorous. This way of thinking can also transpire when one conceives of the practice of physical exercises as a source of energy and well-being, and, at other times, paradoxically, as energy expenditure to be replenished by food or repaired through rest and sleep (Brook 1986; Solomon 1992). Jin and Wei (2014) searched for meanings about energy in dictionaries, adopting thematic analysis techniques that allowed, by association with key ideas, finding semantic patterns in the use of the energy concept in the different spheres of social life. When comparing results from acknowledged English-language dictionaries, they found one definition of energy to be "physical or mental strength." Such a conceptualization sometimes does not differentiate between physical and mental states, or between psychological and biological domains. This is exemplified in phrases such as "children are full of energy" or "she invested all her energy in this project." From an epistemological point of view, the vitalist conception of energy resembles sensualist thinking, since energy is understood as something that can be felt or perceived. It also exhibits an essentialist commitment: living beings are considered energetic on their own.

In the history of science, the energy reductionism proposed by Helmholtz and Meyer supplanted vitalism in biological thinking. According to El-Hani and Emmeche (2000, p. 237), "the 'resolution of the debate' between vitalism and mechanicism was not a mechanistic stance, but a sort of historical compromise in the form of what we here call mainstream organicism," which conceive life as an emergent property of systems (Elkana 1974; Mayr 1997), not necessarily implying a vitalist way of thinking about energy.

3.2 Zone 2: Energy as a (Functional) Activity—the Empiricist Zone

This zone of the profile is relative to what energy can do and to things that are conceived as a result of energy. A first intuition is linked to movement. Energy is what one needs to have in

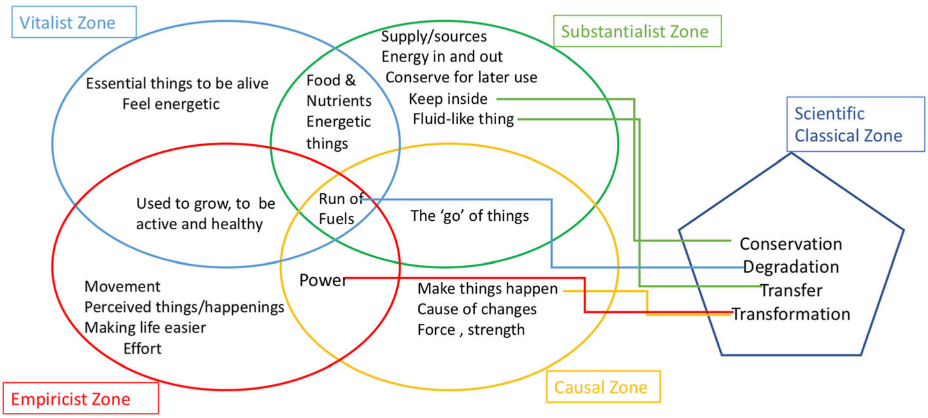

Fig. 1 Map of the zones of the energy conceptual profile model, showing overlaps of zones related to everyday meanings of energy (The expression "the 'go' of things" was used by Jon Ogborn in a paper entitled Energy and fuel: the meaning of 'the go of things' published in the book Energy Matters in 1986. According to the author: "energy is not the 'go' of things, despite the common belief that it is. That is, the possession of energy is not what drives, gives potential for, explains, or accounts for change. Yet, it is very much how energy is presented, and we have a strong sense (which can be traced at least as far back as Meyer's reliance on the conservation of cause in his presentation of the conservation of energy) of energy as the cause of things" (Ogborn 1986, p. 59). In the paper, Ogborn translates this intuitive idea by the scientific concept of free energy or exergy (Gibb's function).)

order to move and to be active. It often means to be in movement. Without energy, machines and living beings become inert and inoperative. Fire and explosions are also considered to be evident effects of energy and somehow connected to the notion of motion. Not without reason, the English-language Webster-Merriam Dictionary designates “dynamic quality” as one of the definitions of energy.

According to Coelho (2009), the word “energy” was commonly used in the eighteenth century with an etymological meaning of “activity,” and with this sense it was used by authors like Seebeck, Ampère, Faraday, Mayer, and William Thompson. The latter used the word energy in 1851 to refer to the mechanical activity of a body. The meaning of energy as activity is often associated with a functional view that identifies energy as something useful for some purpose. Energy is thus associated with processes that make life more pleasant, through practical activities. Thus, this zone has epistemological commitments with empiricism (energy is something that can be experienced as movement) and finalism (energy descriptions based on purposes and goals). In some cases, students extend the idea of mechanical action to heat (movement of particles) and electricity (movement of electric charges).

3.3 Zone 3: Energy as a Quasi-Material Substance—the Substantialist Zone

Substantialism is an ontological commitment found in many studies to be characteristic of the ways of thinking of energy in everyday life (Chi et al. 1994; Wiser and Carey 1983). Sometimes energy appears as the fuel or food itself, or as a subtle fluid contained in food and fuel. Watts (1983) called this way of structuring spontaneous thinking the “depository model of energy.” Conserving energy, in this sense, means preserving (or using sparingly) the fuel. In examining biological processes, students often confuse matter with energy, for example, by stating that “glucose is energy,” “plants turn sunlight into food,” and “a man lost weight by turning his fat into energy” (Dauer et al. 2014).

According to the linguistic perspective of Lakoff and a collaborator (Lakoff 1987; Lakoff and Johnson 2003), human cognition is based on metaphors and many of them are built up from our perceptual experiences. These experiences are combined and compose complex mental representations used and communicated through language and, in this way, structure our interpretations of the physical world and of ourselves. As we use mind and body to create such representations, several of these metaphors are based on the idea of something material and “embedded.” The identification of these metaphors occurs through linguistic analysis, such as those used in the identification of ways of speaking in the Conceptual Profile Theory.

In everyday language it is common to find a way of speaking of energy by using a “conduit metaphor”: energy can be contained in matter or objects, spatially localized, transferred from place to place, or kept for later use. This metaphor is frequently used with educational purposes to deal with energy flows or to account for the energy balance in a given system. Thus, treating energy as a substance in some cases appears as an obstacle (as in “the fuel has ended because the car has used its energy”), while in other cases it offers a bridge to scientific meanings (as in diagrams of energy flow between systems). In the first case, the argument is essentially non-conservative: energy is spent as fuel is spent and, once used, must be replenished or recharged. In the second case, accounting can express the idea of preserving the original quantity, such as the blocks of the boy “Dennis the Menace,” in Feynman’s famous story (Feynman et al. 1966). The strangeness of this allegory, as Coopersmith (2015) has pointed out, is precisely the fact that there are no blocks (i.e., energy is an abstract quantity).

The substantial character attributed to the concept of energy in everyday language is highlighted in Millar's description:

> In the intervening four centuries, the word 'energy' has passed into everyday spoken and written discourse. We can say that someone is 'full of energy', or 'has no energy'. Advertisements claim that certain foods or drinks 'give you instant energy', or 'an energy boost'. In news reports and other kinds of public information, energy is something we 'use' and 'consume'. We buy it from the 'energy utilities'. We are advised to insulate our homes, switch to new types of central heating boiler or car engine or light bulbs, in order to 'save' (or not to 'waste') energy. Governments publish data annually on 'energy use' and 'energy consumption' in different sectors of the economy (industry, transport, domestic, and so on), and debates rumble on about how we can meet our future 'energy needs'. In this discourse, energy is a commodity or resource. It comes in different forms, and from different places. We buy it and use it. When it's used, it's gone. (Millar 2014, p. 188)

In science education research, Chi, Slotta and their colleagues (Chi et al. 1994; Slotta et al. 1995) argued in a series of articles that, in several cases, the persistence of intuitive notions was due to the need to overcome some ontological models. Thus, while intuitive thinking interprets phenomena such as heat, energy, electrical current, and diffusion as belonging to the ontological category of *matter*, scientific thinking conceptualizes them as belonging to the category of *processes*.

In a debate published in the *Journal of the Learning Sciences*, Gupta et al. (2010) challenged the static nature of the model of ontological change proposed by Chi and Slotta. Rather, they advocated for a dynamic model in which individuals operate more flexibly in the ontological realms by acting pragmatically in specific contexts. The authors presented evidence that this would be the case for both novices and experts. In examining models and analogies proposed by novices, the authors concluded that intuitive physics is not restricted to matter ontology and that the students can move productively between diverse ontological categories (including process-based reasoning). Similarly, in analyzing scientific discourse in specialized journals, these authors identified the productive use of ontologies based on matter and processes. They further argued that reasoning based on material attributes can yield productive metaphors for the understanding of more abstract scientific ideas such as conservation principles. This dynamic and flexible interpretation of the epistemological commitments used by the subjects is compatible with the Conceptual Profile Theory:

> Stability, in such a view, need not reflect the properties of a fixed structure. (…) Most relevant here is contextual stability, in which the stability of a pattern of resource activations involves features of the situation. That is, given a situation, patterns may arise and be robust that would not form in other situations. (Hammer et al. 2011, p. 165)

In other contexts, the substantialist ontology for energy is considered to be problematic. To understand ecological processes, many authors (Dauer et al. 2014; Jin and Anderson 2012; Jin and Wei 2014) have argued that a fundamental step is the differentiation between energy and matter. Cycles of matter in ecosystems are closed, unlike cycles of energy. In turn, accounting between energy entering and leaving the system requires thinking of a quantity that is conserved and demands an ability to track energy through physical and biochemical processes.

Another obstacle is the fact that energy is not a property of things themselves, but of systems. Energy is a relational concept, and thus must be identified with interacting systems. For example, gravitational potential energy is not a property of the stone itself, at a certain height, but of the "stone plus Earth system" or "stone plus gravitational field" configuration (Pacca and Henrique 2004). According to Coelho (2009), a similar argument was used by

Hertz in 1894: "the quantity of a substance depends upon the substance itself and not on the existence of other substances, whereas the potential energy of a body is dependent on other bodies" (Coelho 2009, p. 977).

3.4 Zone 4: Energy as a Causal Agent—the Causal Zone

The fourth zone of the energy profile model attributes to energy the cause of phenomena or processes. The general statement is that energy is what "makes things happen" (Holman 1986). In part, causal reasoning may be subtly present when one speaks of energy as the "ability to perform work or to produce transformations." If a transformation occurs, then it is because the energy has acted.

Ogborn (1986) offered several examples: a candle emits light because the flame has energy, a ball falls because it has kinetic energy, the grass grows because it receives energy from the sun, and we run because we get energy from food. According to Ogborn, this causal reasoning does not correspond to the scientific concept of energy. The Laws of Thermodynamics are not causal models. They are only statements that constrain the transformations that can happen. Thermodynamics simply states that processes in which the total energy is not conserved, or the entropy of the system and neighborhood is reduced, simply do not happen.

Many teaching materials suggest expressions that are based on these causal intuitions: "energy is what makes it happen" and "energy is the source of processes and transformations." This causal relation between energy and events is not in accordance with the thermodynamic view, which treats energy as something "necessary in the evolution of processes in technology and nature, just as energy results from these same processes" (Duit 1986, p. 93).

The causal approach to energy may constitute a verbal obstacle, in the sense proposed by Bachelard (2002), that is, as a concrete word that replaces an abstract theory, such that its allusion would seemingly suffice to explain the phenomenon. Thus, the concept of energy must be accompanied throughout the curriculum by causal models for the various domains of phenomena to which it applies. Thus, we speak of energy applied to electrical circuits, to thermal processes, to wave phenomena, but in each of them we can identify corresponding causal agents: the electric field inside the wires explaining the electric current, the temperature differences explaining the heat flow, the vibration of layers of air explaining the propagation of sound, and so on. Such an approach requires differentiating concepts and establishing relationships between them, such as strength and energy, field and energy, temperature, and energy, among others. A similar argument was made by Tobin et al. (2018, p. 5), who suggested that "energy ideas do not provide the mechanistic, causal explanation that we often seek in science. Energy arguments can help us understand, for example, that the energy of (most) life on Earth comes from the Sun, but they do little to elucidate how photosynthesis works."

Causal reasoning in energy can also be understood as an historical precursor to the scientific meaning of energy. Among others, Faraday, Mayer, and Helmoltz used the word "force" and "conservation of forces in nature" to mean "causes" of events. According to Coelho (2009, p. 462), Mayer applied to forces the classical saying, *causa aequat effectum*. In other words, if a cause c originates an effect e and this becomes a cause of event f, Mayer deduced that $c = e = f \ldots = c$, and thus, forces are quantitatively indestructible, qualitatively transformable, and imponderable.

3.5 Zone 5: Energy as a Quantity That Is Conserved and Degraded—the Scientific Classical Zone

This zone of the energy profile model basically translates the understanding of energy from a thermodynamic point of view. Through historical analysis, it can be said that the scientific conceptualization of energy has as a central aspect the General Principle of Conservation. However, this idea relies on others, such as transformation, transfer, and degradation (Duit 1986).

The idea of transformation is fundamental, since energy comes in many forms,[5] being fundamental to the recognition of the indicators of energy in a given system. However, as a relational concept, this identification goes through the transformations that it can entail. Thus, we assign potential energy to the stone-gravitational field system, by which we associate it with the energy transferred to it by lifting the stone in the field or the energy transformed into kinetic energy by the falling stone. Spontaneous thinking more readily identifies sources than forms of energy. Thus, for example, students recognize hydraulic energy and fuel energy, but may not know exactly how water or fuel can have or transfer energy.

In physics, it can be said that two forms of energy would suffice to describe all the processes: kinetic energy, relative to the movement of particles or parts of one system in relation to another, and potential energy, relative to the interactions and configurations of a given system. Such a generalization, however, is not easily understood at the initial levels of schooling, nor is it useful for the study of chemical, biological, or geophysical processes.

Some authors (Ellse 1988; Millar 2014) have contested the curricular emphasis on energy transformations, arguing that it focuses attention on the wrong place, namely, on the "form" of the energy at different points, which does not help understanding. Instead, they suggested a focus on energy transfers, and particularly on the processes through which energy is transferred from one place to another (heat, electricity, radiation, among others). However, even Millar (2014) recognized that the identification of energy forms is a necessary condition for tracing the energy paths in the systems.

As we have said, to approach energy through flows and transfers of energy almost inevitably involves the consideration of energy as a quasi-material quantity, something that can be stored and transferred from one system to another. Thus, it is necessary to teach students how to recognize patterns and processes through which (or in which) energy is involved. Another problem is to quantify and compare the processes in order to account for inputs and outputs of energy in a given system.

Finally, the conservation of energy in real systems demands the idea of degradation. The degradation of energy can be explained and explored in different ways, and at different levels of abstraction. Traditionally, it has been neglected in physics teaching at the high school level, since there are no calculation procedures to account for it without a solid base in statistical mechanics. However, without understanding energy degradation, the idea of energy conservation simply does not make sense. For Solomon (1992, p. 121), energy degradation and conservation must be taught simultaneously, answering two questions: (1) Is energy

[5] This is, in some ways, analogous to the sense that matter comes in many forms (e.g., different phases of the same matter or different allotropes of an element). However, the forms-of-matter analogy is not mapped to energy in many forms when considering types of matter (e.g., different elements or structural isomers with the same molecular formula) vs. types of energy, since conservation of energy provides for transformations between types of energy, while conservation of matter does not uniformly imply the same for matter (e.g., elements do not change identity, though structural isomers can sometimes be interconverted).

increasing, decreasing, or does it remain the same? (conservation) and (2) In what direction is the energy transferred? (degradation). According to her, students should understand that energy moves in certain directions and not with equal ease in others. In addition, energy is dissipated and, thus, processes come to an end.

3.6 Energy as a Discrete Quantity, Related to Wave Function and Rest Mass—the Scientific Modern Zone

While the previous zone expresses classical rationality in science, consolidated with the laws of thermodynamics, here we deal with a conceptualization based on quantum mechanics and the theory of relativity. Two central ideas characterize this zone of the profile: (1) energy is a discrete quantity, associated with characteristics of the wave function of the corresponding matter/radiation, and (2) energy corresponds to the resting mass of a particle, which unifies the principles of conservation of mass and energy, classically treated independently. Here, we only mention this zone of the profile since, in the classrooms that we observed, these meanings were not evoked or placed into negotiation with the students.

The quantum and relativistic view of the universe is expressed through grammatical metaphors, without the mapping of domains of an analogical relation or similarity (Brookes and Etkina 2007). Thus, for example, when it is said that “the electron is in the ground state,” this grammatical metaphor does not refer to the localization of the electron, but to the energetic state that it possesses in a given configuration. According to Brookes and Etkina (2007), physicists use such metaphors flexibly (electrons are treated as particles or waves), depending on the problems treated. The authors distinguish grammatical ontology (indicated by modes of speech, such as “electron beam”) from a lexical ontology that expresses worldviews about matter, states, and processes shared by the community of physicists. Thus, while professional physicists use metaphors flexibly and productively, students may have conceptual difficulties because they tend to interpret them literally.

4 Negotiating Meanings About Energy in a Physics School Class

We followed lessons of a teaching sequence on mechanical energy in a large urban school in the Boston area, whose curriculum, informed by NGSS (2013), is geared toward STEM. The students were in the 11th grade, and came from broadly diverse social and ethnic backgrounds. At this school of approximately 1500 students, almost half them speak a language other than English at home, whereas about 70 different languages are spoken by students in the school. Most students in the physics class had a medium to high academic profile, and they came from a full range of socioeconomic backgrounds (e.g., ranging from parents having a primary school education to having earned postgraduate degrees). The teacher (codenamed Terra) had been teaching physics for 7 years. She has a master’s degree in physics education and continues to enroll frequently in professional development courses.

Terra initiated her approach to mechanics in this physics course with basic kinematic concepts, and after this she addressed energy. She justified working with energy before studying Newton’s laws because, in her opinion, it is more related to the students’ intuitive ideas:

> I recently started teaching energy closer to the beginning of the year, because when I would teach forces first, they always felt really non-intuitive for students. They're also just harder. And energy, when we got to it, always felt more intuitive, easier for students to think about and work through, and also had connections to things they already learned in their other science classes. So, in general, I want to make sure that when introducing a topic, students have some hands-on experience to discover that before I give them the ideas or concepts.

For 5 weeks, we followed 16 lessons of 70 min each. Terra's approach to teaching mechanical energy is shown in Table 3. We discuss in detail some teaching events in the first, third, and 13th lessons, because in these lessons the focus was on the conceptual understanding of the energy concept, with more intentional dialogs between everyday and scientific concepts. The first author made field notes of all the lessons. Some lessons were audio- or video-recorded and later transcribed. The study was approved by the ethics board of the university (protocol 2012–133) as well as by the school district. The teacher provided written informed consent, and the students whose data were analyzed did so as well, along with parent consent if the students were aged 17 or younger.

From the research data (field notes, audio- and video-recorded data), we sought to reconstruct the explanatory structure adopted by the teacher that led to the teaching narrative about the energy concept (Ogborn et al. 1996). That is, we tried to identify the resources and strategies used by the teacher to introduce and develop scientific ideas in the social plane of the classroom. For this, it was important to establish a relationship between the micro-context (discursive and multimodal interactions between the teacher and students, when seen in detail) and the meso-context (construction of a coherent teaching narrative throughout the classes). We found that at some points in the teaching sequence the focus was not on the development of concepts but on activities oriented toward learning to do science and learning about science as a process of inquiry. In our analysis, we focused

Table 3 Lessons of Terra's teaching sequence on mechanical energy

Meeting	Content and approach
1	What do you know about energy? Group work: students designed experiments to explore different ways to measure the smashed-ness of a clay ball.
2	Group-based inquiry work to determine factors involved in the smoothness of clay.
3	Which of these has more energy? Introduction by the teacher to forms of energy and ways to calculate them.
4	Students define gravitational potential energy (GPE) in their own words. Energy card sort (GPE and kinetic energy (KE)).
5	Who has more energy? Students work on exercises to calculate GPE, KE, and elastic potential energy (EPE).
6 to 12	Ramp problem. Students engage in design, predictions, measurements, data analysis, graphs, conclusions, peer review, reporting, and discussions.
13	What does energy have to do with it? Introduction by the teacher to the Law of Conservation of Energy.
14 to 16	PhET simulation: energy skate park.[a] Students are introduced to a new energy change representation, and stimulated to use energy bar graphs to represent some situations (PhET simulation and others, like the marble rolling down the ramp).

[a] See https://phet.colorado.edu/en/simulation/energy-skate-park-basics

attention on the activities in which the focus of the teacher's interventions and students' work was centered on the development of the concept of energy. In order to analyze the process of constructing the teaching narrative of the teacher and the negotiation of meanings about energy between the teacher and the students, we use the zones of the energy conceptual profile presented above.

The teacher started the first lesson with a Do Now activity, giving 5 min to the students to provide answers, followed by a whole class discussion. The question was "What do you know about energy? How would you define it?" In discussion with her classmates, one girl commented: "It is something that you know, but it's hard to put in the paper." Next, she consulted the Internet (using her cellphone), read an academic definition, and translated it into her own words: "energy is the strength we need to do anything." In the discussion that followed, the teacher asked for responses, and she collected some of the students' ideas on a slide that she projected for the class[6]:

1. What every living being needs to do anything in life (Z1)
2. Source of power that helps generate daily things (Z2 + Z4)
3. Things we use to create power for objects (non-living things like cars, buildings, batteries) (Z2 + Z4)
4. Created (generator) or stored (battery) (Z3)
5. Cannot be destroyed (Z5)
6. When it passes through the food chain it becomes "weaker" (Z5 + Z3)
7. Comes back around (Z3)
8. Circle of life (Z3 + Z1)
9. Newton's cradle (Z2 + Z5)
10. Energy divides until there is not any left, hitting kinetic energy (Z3).

In the discussion, students' drew on their biology classes as they talked about the loss of energy as it passes through the various trophic levels (item 6). The teacher asked "and where does [energy] go?"; the students did not know how to respond. Some answers were "I don't know," "to the air," and "that's weird." In such biological contexts, we observed that the meanings of degradation and energy transfer prevailed, to the detriment of the idea of conservation. Substantial metaphors were widely used (as in 6, 7, 8, and 10) and, in some of them, energy appeared as a subtle matter, the quality of which vanishes without preservation of the original quantity. One student mentioned pendulums (items 9 and 10) and, when the teacher asked why a pendulum stops at the end, the student ironically answered "because it gets tired." Another one said, "because of an unbalanced force." "Friction?" asked Terra. We heard both "yes" and "no" answers, without justification.

Some of these responses may belong simultaneously to more than one zone, such as "circle of life," which can encompass the idea of energy moving from place to place (Z3 substantialist zone) and the idea of an essential thing for living beings (Z1 vitalist zone). We identify the vitalist zone in items 1 and 8; the empiricist zone (Z2) in items 2, 3, and 9; the substantialist zone in items 4, 6, 7, 8, and 10; the causal zone (Z4) in items 2 and 3; and the scientific classical zone (Z5) in items 5, 6, and 9.

The teacher then presented an inquiry-based activity: the students were challenged to design and conduct an experiment exploring different ways to measure the smashedness of a clay. (The

[6] We reproduce the sentences in the way they were annotated by the teacher (including quotation marks); they reveal both the students' ways of talking and the importance the teacher attributed to them. We added codes in parentheses (Z1 to Z5) referring to the zones of the energy concept profile, and numbers (1 to 10), to facilitate references in the text.

explicit challenge shown to the class was "Splat: How can you change the shape of a ball of clay? What does that mean about ENERGY?"). The explicit purpose told to the students by the teacher was to "demonstrate your understanding of energy determining the factors that affect the energy of an object."

In the preparation for this activity, Terra offered students a definition of energy by projecting it on the board. She continued to refer to this definition during the remainder of the teaching sequence: "Energy is the ability to create change. It is something an object 'has' (unlike force, which an object 'applies')." This is an approximation to the classical "energy as ability of doing work," avoiding the ambiguity of the "work" concept (a mathematical definition that does not correspond to the idea of work in everyday language). Terra's definition also refers to the causal zone (Z4, energy as the cause of the processes). In later conversation with the teacher, she justified her choice of this definition by explaining that it is closer to the students' intuitions, but she added the caveat that she runs the risk of making energy undifferentiated from force. She said that she had planned to take up the differentiation between the concepts of force and energy when she later introduced the concept of work and the work-energy theorem. Based on this, we consider that Terra was trying to bridge the gap between students' ideas (power of doing things) and the scientific idea of energy as a quantity related to the capacity of bringing about changes.

In the "splat activity," students were encouraged to find ways of smashing the clay without putting their hands on the clay. They were asked to express the variables involved, and how to measure the effects of these variables on the resulting shape of the clay. The five groups of students we observed proposed different solutions to the problem: throwing the ball against a wall controlling the movement of the arm at the launch (group 1) or controlling the distance between the launch and the wall (group 2), dropping books on the clay ball by controlling the number of books (group 3) or the falling height of the book (group 4), and throwing the ball with an elastic band (group 5, but after no success in the launches, this group adopted the same procedure as group 4).

In the beginning of the third lesson, the teacher introduced the forms of mechanical energy, starting with a qualitative problem and then afterward presenting some evidence for consideration from the students' conclusions in the "splat activity."

DO NOW:

Which of these do you think has the most energy? Why?

a) An airplane flying from Boston to Chicago
b) A bullet flying a few feet above the ground
c) A T-Rex taking a leisurely stroll
d) An explorer standing on the top of Mt. Everest.

The students brought many different ideas to this discussion. Some examples were as follows:

- "The bullet itself doesn't have energy, it depends on the gun or how I shot it."
- "The bullet because it is fired"; "the airplane, because it is heavier."
- "It depends on the time period. To the shot, it takes a minute, the flight takes two hours. So, the airplane takes more energy."
- "It weighs a lot, to put it in flight you have to give to it much more energy."
- "The dinosaur has a lot of chemical energy."

From this and the clay experiment, the teacher then provided students with three formal terms and abbreviations of them that the class would use from this point forward: gravitational potential energy (GPE), kinetic energy (KE), and elastic potential energy (EPE). She asked students to connect their clay experiences to observable variables (mass/weight, height, velocity, spring constant, and deformation). She gave numbers to the four situations used in the “Do now” activity, presented formulas, and made calculations with the students for each case.

We see here the teacher introducing new aspects of the energy concept, related to the scientific classical zone (Z5). First, an object can have energy even when not moving, depending on the configuration (in a high position or being pushed by a rubber band). Second, the energy is not an observable quantity, but the amount of energy can be calculated by means of certain variables involved, such as mass, velocity, and height. Third, comparing the amount of energy in different objects (bullet, airplane, dinosaur, or mountaineer) means comparing the amount of changes that these objects can absorb or release upon returning to an initial configuration. This can also be done by relating the amount of energy of an object in a given configuration to the amount of fuel needed to put it in that condition. The causal definition used by the teacher was very productive in the sense that it generated new meanings, operating as a valuable resource in the progress of the students’ understanding of energy (Scherr and Robertson 2015).

In the fourth and fifth lessons, we see the teacher reinforcing the concept of gravitational potential energy and kinetic energy through qualitative and quantitative problems. Between lessons 6 and 12, students worked in small groups with another inquiry activity: given a set of wooden ramps, they should propose and develop measurements to indicate which feature of the ramp (height, base, or slope) would be related to the final speed of a marble launched from the highest point.

During the ramp activity, shown in Fig. 2, students worked in groups. They were provided with marbles and 14 different ramps, labeled A through N. They made predictions of which ramp would result in the fastest speed of a marble at the end of each ramp. Then they designed experiments to relate ramp dimensions to the end-of-ramp velocity of a marble. They made measurements and ranked the speeds of the marble on each ramp. They constructed graphs for their variables of interest, such as height vs. velocity, slope vs. velocity, and base length vs.

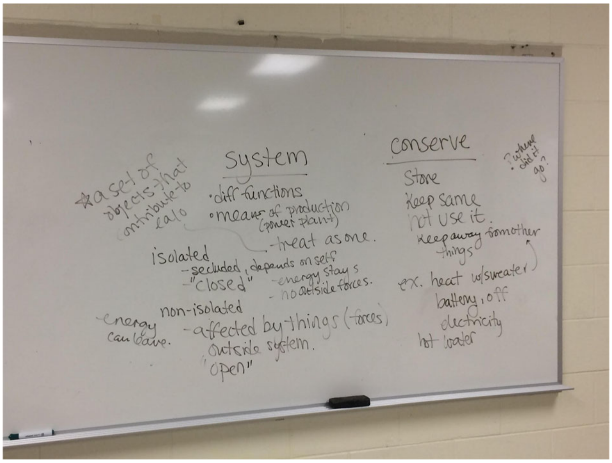

Fig. 2 Teacher’s notes written on the board, based on the discussion with the students, showing that she welcomed their ideas and elaborated new ideas based on them

velocity. Then they discussed the correlations among variables and drew conclusions. Afterward, the class compared the conclusions and data from all of the groups and made final conclusions as a class.

During the ramp activity, the students did not explicitly use energy concepts in their predictions or explanations. Most of the predictions and explanations were based on intuitions of the students about time and speeding up, and on kinematics reasoning. The concept of energy returned to the discussion only during the final conclusions phase, at the end of the 12th lesson.

The 13th lesson began with students reading a paragraph and engaging in an activity about the Law of Conservation of Mechanical Energy, which is reproduced below.[7]

ENERGIZING PHYSICS LESSON 2.4.
WHAT DOES ENERGY HAVE TO DO WITH IT?

Energy gives a system the ability to produce change in itself or the environment. **The Law of Conservation of Energy** states that the total amount of energy in an isolated system remains constant. This law, one of the most important in all of science, has no known exception and applies to all sorts of natural phenomenon, such as a swinging pendulum, a biological system, and riding a bike. In this lesson, you will connect energy and this law to justify the results of the ramp experiments.

1. (Energizing question) Let's first develop some terminology related to energy.
a) What does it mean to conserve something?
b) Provide an example of when you conserved something.
c) The Law of Conservation alludes to a "system." What is a system? Provide an example.
d) What is the difference between an isolated system and a non-isolated system?

The teacher gave students 5 min to read the text and answer the questions before opening a whole-class discussion. In the group of students that we followed during this activity, the four girls wrote in their notebooks the answers to question (a) and then shared them aloud. These are listed in the order in which the students shared their answers with each other during the discussion. Students are labeled S1 for student 1, S2 for student 2, etc.

- S9 said that to "conserve something" is "saving it."
- S1 said conserving something is to "keep or hold something."
- S7 added that it is "to keep; remain constant."
- S2 said that it means "to save energy, to contain it."

With the exception of S7, who used a scientific meaning for "conserving energy," the others relied on a substantialist viewpoint: to conserve energy, i.e., one keeps or holds it for later use, as something material that can be kept apart.

In item (b), three of the students mentioned "sleeping." S9 offered "turning off the lights." We interpret the sleeping example of conserving energy as related to the vitalist zone (Z1), because it refers mainly to one's personal experience of being active and lively after rest. Thus, using their general knowledge, the students did not maintain one single meaning for the concept of energy. On the contrary, they moved from one meaning or mode of speaking to another, without awareness of change. In this case, the students moved from a substantialist (Z3) definition for conserving energy to a vitalist (Z1) example of it. This result is consistent with other studies that conceive of "natural thinking" (Guidoni 1985) as being composed of

[7] This activity as well the proposal of the ramp experiment was taken from the book "Energizing Physics" (Osowiecki and Southwick 2012).

multiple and potentially contradictory models, used in a flexible way depending on the situation.

Part of the class discussion of the question on the meaning of conservation is provided in Episode 1 below.

Episode 1. What does it mean to conserve something?

1 ***T:*** Okay, guys. So what does it mean to conserve something?

2 ***S1:*** To store.

3 ***T:*** To store it? Okay. [?] to store it. Anyone else got a definition?

4 ***S2:*** To keep it the same.

5 ***T:*** To keep it the same. Anything else?—did you have a hand? No? Store, keep same—what did you say?

6 ***S3:*** Not using it.

7 ***T:*** Not using it. Cool. Do you have an example? Oh yeah.

8 ***S4:*** Isolate.

9 ***T:*** Isolate? What do you mean by that?

10 ***S4:*** Never mind.

11 ***T:*** Never mind? What do you mean?

12 ***S2:*** It ((referring to the text)) said isolate, but what does isolate mean?

13 ***T:*** Isolated. Okay, so like to keep it away from other things, isolate?

14 ***S4:*** Hide.

15 ***T:*** And—what do you have?

16 ***S5:*** As an example of it?

17 ***T:*** Sure, yeah.

18 ***S5:*** Conserve heat.

19 ***T:*** Conserve heat? How do you conserve heat?

20 ***S5:*** Like wearing a sweater.

21 ***T:*** Okay. Yeah, so you wear a sweater to keep the heat in, as opposed to letting it go leave your body, so like you are keeping that heat away from the outside environment. Okay. Yeah?

22 ***S6:*** When you turn the phone off to like keep the batteries.

23 ***T:*** Conserve battery by turning it off. So is that conserving energy?

24 ***S2:*** So, yeah, you are not using it.

25 ***T:*** Conserving like the battery, the energy that the battery's storing. If you uhh.

26 ***S2:*** [Go to sleep].

27 ***T:*** [If you did not turn your phone off and you were not conserving your battery, where would that energy from your battery be going?

28 ***S2:*** In the air.

29 ***S4:*** It would be being used.

30 ***S?:*** Into the apps.

31 ***S6:*** The government.

32 ***T:*** The internet?

33 ***S4:*** It would be, being used up by us.

34 ***T:*** Yeah. Where does it, what is it being used to do?

35 ***S1:*** Like operate the phone.

36 ***T:*** Operate the phone. [?] so the government can keep tabs on us? Okay. Like what is our phone doing that's using this energy? Like what does it become?

37 ***S5:*** It's become like, you know, using a phone. It's on. You charge it.

38 ***S?:*** Well, you use it all up, it dies.

39 ***T:*** And then it's gone?

40 ***S4:*** No, then you recharge it again.

41 ***T:*** But where would it go?

Asking, "What does it mean to conserve something?," the teacher elicited students' everyday knowledge. The students' answers were at odds with the text they just read about the Law of Conservation of Energy (in isolated systems). Nevertheless, the teacher prompted students' ideas and welcomed them, writing some answers in the board (shown in Fig. 2). The substantialist view (Z3) prevailed in students' answers: energy is something material or quasi-material that you can store, keep apart, or simply just not use. At the same time, the students gave meaning to the word "isolated" used in the text (turns 8 to 14). In this, the teacher suggested the idea of keeping it away from other things (turn 13) and S5 built an analogy with conserving heat, like using a sweater. The teacher welcomed this idea and repeated it, using expressions such as "keep it in" "letting it go" or "keeping that heat away from the outside environment" (turn 21). Thus, we see both the students and the teacher negotiating meanings starting from a substantialist view of energy. There is also a functional (Z2) meaning of energy present (turns 6, 24, 29, and 34), as something used up for certain purposes. In turn 26, S4 used an embodied metaphor, exemplifying conserving energy as sleeping, or restoring energy, like a cellphone battery. At the same time, the teacher prompted students to think about where would the energy of a cellphone be going (turn 27) or what it would become (turn 36). By doing that, she encouraged students to track energy fluxes in the operation of appliances. Again, the modes of speaking reveal mainly a substantialist viewpoint (Z3), such as when the teacher asked "and then it's gone?" and "where would it go?" (turns 39 and 41).

Later in the same discussion, the teacher and the students worked with the concept of "system" that was mentioned in the text. An excerpt from this discussion is shown in Episode 2.

Episode 2. How about a system?

65 ***T:*** Okay. Cool. How about a system? What's a system?

66 ***S3:*** You know, like a place that [?].

67 ***T:*** Okay. A place that [?] is a system?

68 ***S3:*** Yeah.

69 ***T:*** Like a [?]?

70 ***S4:*** It's like something that has multiple working parts.

71 ***S2:*** A system is made up of different functions.

72 ***T:*** Okay, so you can have different functions. Okay. Anything else, definition of a system?

73 ***S7:*** Channels or means of production.

74 ***T:*** Channels or means of production. Okay, and do you have an example of that? No example?

75 ***S8:*** A power plant.

76 ***T:*** A power plant. Okay. Okay, so a power plant is a system. Okay. Okay, [?], what were you going to say?

77 ***S8:*** I said a set of things that contribute to each other.

78 ***T:*** Okay, yeah. So I think that a set of objects that contribute to each other requires that they interact with each other. And then in physics, when we talk about a system, we are going to talk about a set of objects that interact with each other that are treated together as one thing. So I might have a car, and I have a bunch of different parts of the car, but I am going to treat it as one system. Put it together as one thing, and then if I am thinking about the energy of the

car, I am not thinking about the energy of each individual component. I am thinking about the energy of the whole thing. So a set of objects that contributes to each other or connect to each other, and you treat as one. So that's true. Any other examples of a system?

79 ***S4:*** Oh, circulatory system?

80 ***T:*** Yeah, so like a circulatory system has a lot of different parts, but you treat it as one system. What does it mean for a system to be isolated? Isolated, what does isolated mean?

81 ***S9:*** Secluded.

82 ***T:*** Secluded, okay. So what would that mean for like—So if the system is secluded.

83 ***S2:*** It only depends on one thing.

84 ***T:*** It only depends on—for itself, okay. Secluded.

85 ***S4:*** I was thinking like a closed system. Like there's a boundary.

86 ***T:*** Yeah. So in physics, we might call a system isolated, or we might call it closed. And in physics—Oh, you have something to add?

87 ***S9:*** In the reading, it says that in isolated systems the energy [?]

88 ***T:*** Yeah. So does that mean the energy cannot go? The energy has to stay inside the system, because there's nothing making it or allowing it to—So we also say a closed or isolated system is one where there are not any outside sources affecting it. So the energy stays, and no outside forces. So if you do not have that stuff written down, you should record that. No outside forces. Okay? How about non-isolated? What do you think is happening in a non-isolated system?

89 ***S6:*** It all depends on each other.

90 ***T:*** It depends on—.

91 ***S6:*** Each other.

92 ***T:*** Like other things in the system?

93 ***S6:*** Yes.

94 ***S2:*** No, outside of the system.

95 ***T:*** Things outside of the system. So affected by things outside of the system. So that could be forces outside of the system. So if I come to the car and I push it, and I am outside of the car system, then I am adding some energy into it. I am this outside force. Outside of the system, okay. Cool. Any other word for non-isolated?

96 ***S?:*** I do not know.

97 ***T:*** Okay. So energy. I am going to say can leave, because if energy, if we know from our other science classes that energy cannot be created or destroyed, it can only go from one place to another or transfer from one form to another. So it can leave. Another word for non-isolated? If we are calling isolated closed—.

98 ***Many Students:*** Open.

99 ***T:*** Open. So I might also call it an open system. Okay, guys.

When invited to talk about systems, the students brought ideas from biology (turns 70–71) and home economics (turn 73). From these ideas, the teacher repeated "contribute to each other" as "interact with others" and presented a physics definition: "a set of objects which interact with others but are treated together as one thing." Then, using the metaphor of energy being localized in places and objects, the teacher defined an isolated system, one in which "energy can't go out," "has to stay inside" because "there aren't outside sources affecting it," "no outside forces." In this way, energy conservation is presented as a consequence of the definition of an isolated system, built from a substantialist (Z3) viewpoint. While canonically incorrect, this is fruitful in the teacher's interactions with students, in the same way as others have shown such exchanges to be (Hutchison and Hammer 2010). Such a model demands an idea of energy as a localized quantity, which can be measured, transported, and accounted for.

The students then applied the Law of Conservation of Energy to the mechanical situation of the ramp problem, to dropping and throwing objects, to a roller coaster, and further, to situations involving elastic forces (using a bungee jumping simulation). The idea of "conservation of energy" then became an equation and a basis for calculations with problems of school physics. Working on the PhET simulation "Energy Skate Park,"[8] the students did not appear to be surprised by idealized systems in which the skater returns to the same starting point and continues to move indefinitely. As the students worked on solving school science problems using equations, this lack of surprise, and other similar evidence, marked a move of students' attention away from reconciling their ideas about energy with their work in the classroom.

5 Discussion

In the classroom events described in this article, we can recognize the presence of several zones of the conceptual profile model and their importance in the processes of construction of the scientific concept of energy. The most obvious of these is the substantialist zone (Z3; energy as a quasi-material substance), easily recognizable in metaphors that describe energy as something that can be located in objects, stored, and transferred from one place to another. We have seen how this metaphor was transformed by the teacher to mean the conservation of energy in isolated systems. In turn, and paradoxically, this same metaphor was used by students in clearly non-conservative reasoning. For example, in saying that energy, like a kind of fuel that triggers processes, is spent once used and must then be replenished or recharged.

Scherr and Robertson (2015), as well as others (Hutchison and Hammer 2010), have shown that canonically incorrect ideas, such as "collisions generate heat," may be productive depending on the instructional context. In fact, canonically incorrect ideas can serve as a valuable intellectual raw material that learners use to make intellectual progress. These researchers provide evidence that incorrect ideas may not exclude other correct understandings, but instead can be used to stimulate negotiation of model-based and mechanistic reasoning.

In our view, the problem is not in the metaphors themselves, but in their uses and, above all, in our awareness of them. Scientists in peer-to-peer communication draw heavily on such metaphors, and these uses help them to draw models and interpretations of the physical world. Brookes and Etkina (2007) showed that thermodynamics and quantum mechanics communications use grammatical metaphors to express systems behavior—e.g., the electron is in its ground state; a temperature gradient promotes heat flow that can be described with the same equations as fluid mechanics. However, in scientific thinking, grammatical metaphors do not align with fixed ontological beliefs. On the contrary, their generative character lies in the mobility of models and the flexibility of thinking (Caravita and Halldén 1994; Gupta et al. 2010). The electron is at once described as wave and as particle; what defines one or another description is the phenomena studied and the class of problems that we wish to solve.

In addition to the materialization of processes and phenomena, intuitive thinking uses metaphors that have their origin in the bodily perception of experience with the world, such

[8] https://phet.colorado.edu/sims/html/energy-skate-park-basics/latest/energy-skate-park-basics_en.html

as feeling energized and active or, on the contrary, weak and lack of disposition. It is not a matter of banishing such forms of knowing and speaking about the world, but bringing them to consciousness and making their use productive and context-appropriate.

In the same way, the repertoire of general knowledge is guided by a simple, linear, and direct causality (Rozier and Viennot 1991). A cause is considered as equivalent to an effect, and often cause-effect relationships are so intricate that we do not know how to distinguish them (such as the intuitive notions of force and motion). Scientific thought is not unaware of the importance of causal systems, although it elaborates more sophisticated versions, such as multiple, emergent, reciprocal, statistical, or formal causalities. The principles of conservation are systems of formal causality, rules that indicate what cannot occur, but do not determine from given conditions the future behavior of a system (Kuhn 1977).

In turn, it must be acknowledged that the concept of energy is too general and, when applied to classes of particular phenomena, requires the combined use of specific causal models and a number of other related concepts. Thus, speaking of energy in acoustics is not the same as dealing with energy in electrical circuits, and still less in open systems such as a cell or an ecosystem. All of these demand specific languages, disciplinary concepts, and modeling of the systems at play. However, as a crosscutting concept (NGSS 2013), the central ideas of the scientific concept of energy should be highlighted and compared in each field of application. In Terra’s physics lessons, students mentioned what they had learned in biology classes. Would there be room for a transdisciplinary discourse comparing languages and approaches in one and the other disciplinary field? How does the concept of energy appear in each case? In teaching relationships, as we have seen, the idea of energy as a causal agent can be a bridge to the meaning of scientific ideas. We have seen that the teacher used it to introduce the concepts of gravitational and elastic potential energy. The limits of this are found in the lack of differentiation among force, power, and energy, concepts that are gradually understood by the students.

The Conceptual Profile Theory proposes a productive dialog between different systems of thought or ways of thinking, provided that they are accompanied by the awareness of their potentialities and limitations. It would therefore be advisable to consider that the students are working with two meanings for the same expression “energy conservation.” On the one hand, there are modes of thinking and ways of talking about energy conservation that conceive energy as not-wasting, keeping, or reducing use of energy resources. On the other hand, there are discourses that understand the conservation of energy as a universal principle which states that, in any and all natural or technological processes, the total value of energy remains unchanged. These two discourses need to be brought into contact, to provoke each other. Students need to discuss the apparent paradox between the general statement of the Law of Conservation of Energy and the economic and environmental problems of diminishing or difficult energy supplies in contemporary societies.

A scientific education committed to global citizenship demands a dialog among systems of knowledge. For this, scientific knowledge cannot be just a matter of abstractions and formalisms. Such abstractions need to “ascend to the concrete,” to gain life and meaning by being contextualized in themes of daily life and citizenship (Crepalde and Aguiar 2013). Thus, the role of idealized systems in physics must be discussed and understood as powerful mediations that allow us to examine concrete situations from another point of view. For example, if we think of the Earth as a system, we must admit that it is an open system that exchanges energy by means of radiation (radiant energy received from the Sun and energy radiated back into space). The energy balance of this system allows us to predict what happens to the average temperature of our planet and how it evolves over time and with changes in the composition of the atmosphere. We may also consider less complex systems, such as a running engine. It is thus possible to model such a system in terms of energy going in and out according to the Law of Conservation of Energy. Furthermore, even in mechanics, the scientific concept of energy demands an approach expressed by the laws of thermodynamics, where conservation and degradation of energy are inseparable ideas.

6 Conclusion and Implications

In this study, we follow how a physics teacher introduced and developed aspects of the scientific concept of energy in the context of classical mechanics. We witnessed how the teacher elaborated an explanatory structure that was woven into her interactions with the students, blending aspects of the concept of energy in the general domain of daily life and in the school science domain. From the results, we can affirm that the conceptual profile theory and the zones of the energy profile proposed here allowed a comprehensive understanding of the processes of negotiation and meaning-making by students in relation to the concept of energy, as these were built by the teacher and students throughout the teaching sequence.

The data and analyses presented in this study strongly support the theoretical claim that the teaching of scientific concepts should take into account the diversity of ways of speaking and thinking that are manifested in different contexts of social life. In order to model the heterogeneity of verbal thinking about energy, we proposed a conceptual profile of energy composed by six relatively stable zones, each grounded in specific ontological and epistemological commitments, and expressing ways of speaking and modes of thinking about the concept of energy in society. We show how each of these zones can, paradoxically, engender both obstacles and bridges to the meaning of the scientific concept of energy.

We have shown that a diversity of ways of thinking about energy is inevitably present in the science classroom and can be semantically analyzed by using the Conceptual Profile Theory. On the one hand, students bring everyday knowledge to interpret the scientific concept of energy. On the other hand, teachers selectively rely on some general knowledge as bridges for the introduction of scientific points of view. In this way, we interpret the interaction between the teacher and the students as a process of negotiating meanings, involving the interplay between scientific and everyday conceptualizations, which can be fruitfully interpreted from the zones of the proposed conceptual profile.

In the physics classroom discussed here, we saw how the teacher introduced the concept of gravitational potential energy from the idea of energy as a causal agent capable of producing change (clay activity). We also observed how she relied on the idea of energy as something localized and that can be transferred from place to place to apply the Law of Conservation of Mechanical Energy. However, these energy conservation statements remained restricted to idealized systems, without any mention of energy degradation. Interestingly, at the opening of the teaching sequence, some students mentioned the topic of energy degradation, drawing on the study of energy flows in ecosystems in biology courses. Despite this, the teacher did not return to this idea. If she had, it might have allowed the class to approach and to confront discourses on energy conservation, both in the scientific field and in its uses in daily life.

We can interpret this absence by claiming that the lack of consideration of this heterogeneity of verbal thinking entails the isolation of school science knowledge, which in this case would present itself as a set of inert knowledge, incapable of facing complex problems of contemporary life. While we witnessed an alternation of meanings about energy conservation, no opportunities were given to the students to become aware of them, confronting their senses and contextual uses. We consider this a missed opportunity on the part of the teacher, and we propose that the students might have learned more deeply about energy had she done so. The Conceptual Profile Theory offers guidance for this.

We suggest that that teachers can better elaborate their strategies and teaching approaches from the recognition of different conceptualizations of energy. The zones of the profile can be a reference for teaching design, in both continuity with the knowledge of everyday life and discontinuity resulting from ruptures promoted by the theoretical realms of science. According to the conceptual profile theory, teaching practices should involve two aims: (1) introducing aspects of scientific conceptualization that do not exist in the students' general knowledge and (2) promoting students' awareness of the cultural heterogeneity expressed in the profile model built for a particular concept and, therefore, of the heuristic strength and limitations of the various approaches to the concept and their contexts of validity.

Finally, we recommend that science teachers assist their students in the recognition of central ideas of the concept of energy that pervade the different languages and approaches to the concept in different fields of knowledge. The understanding of the scientific concept of energy, in its comprehensiveness and generality, demands an effort to translate the diverse semiotic and linguistic resources employed in its different contexts of application in biology, physics, chemistry, geosciences, and other relevant subdisciplines of science.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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