SPECIAL FEATURE: ENERGY AND THE ENVIRONMENT

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Lessons that non-scientists can teach us about the concept of energy: a human-centred approach

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Abstract

Energy is not only a core concept in physics but also a major issue in our post-Kyoto world. When using a constructivist approach to teaching, we need to be aware of students' preconceptions. A palette of alternative frameworks, which includes those used by adults within the community, can facilitate this. An exploration of energy issues with non-scientists within the community has generated some relevant insights. Participants' concepts of energy were multifaceted. Most had a strong personal component, but also social, technical and cosmic dimensions. Although many participants were uncomfortable with the terms 'renewable' and 'sustainable', they clearly articulated the social and technical requirements for a shift away from current fossil fuel dependency. However, the law of conservation of energy, a core belief of physicists, appeared to be totally absent from their concept of energy.

Introduction

As the world struggles to come to terms with implications of global climate change, the language associated with energy generation and consumption is changing. Terms such as 'photovoltaic' and 'passive solar', which previously belonged to narrow scientific areas or interest groups, are becoming mainstream. Although the concept of energy is central to the debate much of the associated terminology is both value laden and has subtly different meanings for different disciplines. For example, the term 'biomass' has different connotations to a forester, a power station engineer, an environmental manager and an environmentalist. This diversity of interpretation poses significant challenges to physics teachers.

Energy is a very difficult concept, both for students to grasp and for teachers to teach. Some school physics textbook writers such as Hart *et al* [1] are keenly aware of the difficulties and address these specifically, but many simply present students with the neat, tidy rationalized system that emerged with the development of the SI system of units. In this way the messy history of the subject is obscured and the opportunity to explore conflicts between the narrow physics definition and common daily usage is lost [2].

Many students first meet the term 'energy', as a scientific concept, in their primary school

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classes. In this context, it is often used as a unifying theme both within the physical sciences and between the physical, biological and earth sciences. Although this has the potential to introduce students to diverse forms of energy, it can also cause confusion since the various science disciplines think about energy very differently. In addition, many of the teachers at this level have studied very little physics, so their teaching is somewhat tentative [3]. By the time students arrive at tertiary education they have met energy in a wide range of contexts and at different levels, but students have seldom developed an integrative concept. Hence they remain confused and uncertain about much of the physics of energy. This uncertainty was clearly evident in the results of a survey of first-year tertiary students in the School of Natural Sciences (Edith Cowan University, Perth, Australia) in which students rated their confidence levels in using energy-related terminology. Of the 30 terms given, only 'energy' and 'power' were used with confidence by more than 70% of the students. In class, students often quote '*energy is the ability to do work*' even though this survey showed that they are less confident using the term 'work' than they are 'energy'. The unit of a joule was even less well understood, with only 51% using this term with confidence.

Constructivist ideology makes it imperative that we work with students' prior knowledge and understandings [4, 5]. This can be made easier if we start with a palette of possible interpretations that is as complete and inclusive as possible. Some of the early work on students' understandings of key concepts focused on deviations from the correct scientific standard. This thinking is reflected in the term applied, namely 'misconceptions'. Recently, in line with a constructivist approach, non-standard interpretations have received a more sympathetic treatment, and the term 'alternative frameworks' has been adopted [6–9]. In order to understand these alternative frameworks, and the ways in which students use them to construct their understanding of the world, research has moved from key concepts and familiar mistakes to the broader context of students' experience.

In our research we have moved one step further and have investigated the concept of energy as used by adults in the community. This provides a background for students' understandings by illustrating shades of meaning and alternative frameworks that exist in the broader community. The focus of our research was an exploration of public understanding of energy, and renewable energy in particular, in ways that relied on participants to choose their own language to describe their understandings. This article will outline the concepts of energy that emerged from this study and will provide, where appropriate, comparisons with results from a survey of natural science students. Possible implications for teaching energy, particularly to non-physics specialists, will be discussed.

Use of the terms 'energy' and 'renewable energy' by community members and natural science students

The community participants in our study of the public understanding of renewable energy ranged in age from early thirties to late fifties. All participants classified themselves as non-scientists. While their formal qualifications ranged from non-completion of their formal school education to a university arts degree, they all shared an interest in education. We used images to bridge communication barriers and to minimize the tyranny of jargon. We held six group sessions, each involving about five participants. In the first part of each session, participants worked individually and selected images (pictures, graphics and text) that spoke to them about current use of energy and future possibilities. They then assembled these images into a collage and described their collage and the significance of individual images to the rest of the group [10]. This very open approach enabled us to gain unusual insights into participants' understandings of the issues and their use of terminology.

For participants in our study, 'energy' was a multifaceted term. They used the term in many ways and moved fluidly and unencumbered between the different aspects. For all participants, energy was a human-centred activity. Images of people were included in all the collages with comments such as '*the dancers, the energy they expel is amazing'*. Energy was also the social fabric, the interactions between people and places. One participant described a selection of consumer goods in these terms: '*I feel as though I'm being overpowered, overwhelmed by this... what I call*

the corporate energy'; others talked about the impact that buildings and the natural environment had on them and on society. Energy had both classical and cosmic dimensions with discussion of cars and motorcycles alongside '*energy in the petri dish*', '*birds using thermals*' and '*energy sources from out there, which we don't understand at this stage*'.

While talking about energy in general, participants were confident, but as they began to consider aspects of future energy use and to think about renewable or sustainable energy, they became more hesitant and the level of reflection about meaning and significance increased. As one participant said '*. . . I realize really that [there is] a lot that's missing in my knowledge of renewable energy'*. As participants explained the significance of the images that they had selected, their difficulties with the terminology became increasingly evident. The terms 'renewable', 'sustainable', 'natural' and 'alternative' were all used. For some participants the term 'renewable' meant replaceable. With this very literal interpretation, there are no renewable sources. Some considered the term 'sustainable' to be so politically loaded that they were unwilling to use it and instead chose the term 'natural energy'.

This lack of confidence with the term 'renewable energy' was shared by the first-year natural science students surveyed in August 2002. These students are studying for degrees in biological sciences, environmental management or the health sciences. Only 57% were confident using the term 'renewable energy'. Individual components within renewable energy technologies fared even less well. The term 'geothermal' was used with confidence by 22% and was a completely new term for 32%. The comparable figures for the term 'photovoltaic' were 3% (confident) and 66% (new).

Aspects of renewable energy that the participants explored were the technical, personal, social, environmental and cosmic. All participants considered some of the technical aspects associated with renewable energy so that images of sun, water, wind and ocean abounded. Energy storage was also considered by several participants. One collage and its explanation were particularly memorable: '*the storage of energy and by storing it you get bundles—like I basically put these babies around, they're bundles of energy*'. This contribution also shows the fluidity of the concept of energy and illustrates the way that many participants moved between ideas and made links that do not appear in traditional physics texts.

Participants considered their own personal renewal both at a physical and at a psychological level. They talked about their life experiences and discussed the energy needed for this renewal and their own energy gain as a consequence. One participant considered the renewability of the human body, saying '*that is really interesting because that is why I also want to have these people in this one. Yes, I thought, people are renewable they, you know, they decay. . . they feed the soil again so that other things can grow. . . yes I have to have people in it too and food which gives energy to people*'. The energy for change returned again in the context of the need for community will and leadership to change, as one participant said '*any change for us in this whole area of renewable energy, is not about the technology. The technology is there, it's about whether we will personally allow the technology to happen*'.

Concern for the environment and the need to stop ongoing environmental degradation were themes that ran through most collages. Renewable energy was seen as part of the solution, although attitudes ranged from evangelical to highly sceptical. The cosmic dimension was a recurring theme as participants grappled with the concept of renewability and looked at cycles of change. In this context renewable energy enrolled concepts from physics, geology, astronomy, biology and ecology. Two examples are '*and then we've got a man with the compost which got all sort of living things in it which is used to grow more living things*' and '*a contradiction the whole idea of renewable is because everything seems to be quite final when you look at it. Like the sun,. . . it is certainly renewable in our life time but overall it is not*'.

Discussion

Listening to the non-scientists talking about energy, in this very integrated but qualitative way, forced me to re-examine my own conceptualization. I realized just how evasive, invasive, yet tangible was my own concept. The quantitative runs through the qualitative and teases and plays with it. If I try to focus in on one section of my understanding, new links become evident, the concept

expands and interconnects but does not stand still. It has the quality of the Mandelbrot set [11]. Interestingly, focusing on the formal definition serves to takes me out of this dynamic, interrelated and moving concept. The formal definition has a different flavour and seems very separate, confined and utilitarian although cleverly crafted. Upon reflection I find that I draw on my understanding of its historical development in order to fit it back into the dynamic concept.

In physics, energy is an abstract quantity that is always conserved, it is the currency of the natural world. The parallels between economics, energy and value are explored by Mirowski [12]. In practical terms, the law of conservation of energy lost its status as an independent law and became embedded in the system during the development of the SI system. The single unit of energy replaced the older subject-specific units such as calorie and electron volt. In this rationalized system, energy and work sit at the apex of a pyramid of formal definitions with the fundamental concepts of mass, length and time as the base.

The belief in the law of conservation of energy is so strong that it is a requirement for membership of the physics community. It is an essential part of the physics paradigm [13]. However, the physics concept of energy is not limited to the law of the conservation of energy and the definition of energy. The richness of the concept can easily be exposed by looking at the index of physics texts. Energy is bound, conserved, converted, dissipated, stored, transferred and transformed. It is owned by particles and fields. It is internal, potential, quantized and has mass [14]. It is indeed complex and ephemeral, it dances from wave to particle and defies definition.

The participants in this study did not subscribe to the narrow definition of energy, neither did they seem to understand the law of conservation of energy. This is hardly surprising given the counterintuitive nature of the law and our associated use of language. Terms such as 'wasting energy' and 'losing energy' do not fit comfortably with the law. Without the constraints imposed by a knowledge of and belief in the law of conservation of energy, a few participants proposed perpetual motion systems as alternatives to fossil fuel. This parallels the findings of research carried out with school students [8]. Of the alternative conceptualizations observed in school students, and described by Watts [9], Lijnse [15] and Driver [7], the only one that was clearly recognizable and consistently applied by community participants was the one associated with living things. Life and its associated kinetic, thermal and potential energies were core elements in all descriptions. Although there were elements of energy as causal agent and links between energy and force, the conceptualizations of the adults were more complex and sustainable.

The more qualitative concept of energy that emerged from our study was vibrant and dynamic and had many parallels with that of physics. The ideas of energy transfer, energy conversion and storage were mainstream while the concept of an energy field was latent. The focus on the personal generated a strong link between abundant energy and health. The social dimensions of the challenge to move from fossil fuel use to renewables were clearly articulated. It is interesting to speculate whether this dynamic qualitative concept of energy is indeed closer to the physics concept than that based on the pyramid of definitions. At the start of the study, the technical errors jarred, but by the end of the study the parallels became more evident. It was as if participants were describing physics concepts with a surprising mythological exactitude. I now believe that this approach may well provide a stronger basis for the change in thinking required to embrace a renewable energy future with distributed energy sources than the more formal definition-based one. Ideally both are needed.

Implications

As I now start a module on energy and pollution with a new group of students, I am challenged to think differently about energy and to consider ways in which I can help students gain a richer understanding of issues. I have decided to experiment with leaving out the physicists' core belief, the law of conservation of energy, and instead to focus on the concept of efficiency. This enables me to tap into natural science students' understanding of energy flow, of useful energy and of energy not going where it is meant to go. I hope it will also give me a better basis on which to discuss renewable energy and a less confused and hence alienated student cohort.

Received 30 October 2002
PII: S0031-9120(03)55366-7

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