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Another go at energy

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Abstract

The teaching of energy throws up many different approaches and causes many arguments. This paper describes yet another approach to teaching the subject matter using a system of diagrams, but hopefully one that will be an acceptable compromise for many teachers. Lord Rutherford is often quoted as saying, "All science is either physics or stamp collecting", and the authors realize that this paper falls into the latter category.

(Some figures in this article are in colour only in the electronic version)

M This article features online multimedia enhancements

Introduction

Teaching energy has always been an area that was difficult [1, 2]. Energy itself is an abstract concept and children are mostly taught it when they have only concrete thought to apply [3]. The most successful method one of the authors had used before that described here was using concrete examples. Pupils would concentrate on demonstration equipment set up in the lab and produce descriptions of the energy transfers taking place. This was found to be unsatisfactory simply because the approach seemed to be reinforcing the concrete side. The pupils tended to think of energy as being concrete and it was too closely linked to the examples that they had seen. After looking at a variety of other methods it appeared that a successful method must:

- Be correct in its physics although this didn't need to be rigorous all the way through. A few problems could be ironed out at a later stage if it made life simpler early on.
- Have all the 'labels' in it. The system of labels is too widely used to ignore. The idea of teaching just energy and doing away with the forms of energy is an appealing one but too many users of the forms exist to do this.
- It should also be fun.

The first clue to the final approach was the Boohan/Ogborn diagrams from the ASE's Energy and Change resource. The problem with these was that they were too difficult. One of the criteria used for judging a resource is based around one of the authors' lack of intelligence. If someone who isn't very clever can understand it, then the pupils are in with a fighting chance. If what is presented to the pupils takes a teacher a while to understand then it fails the test. However, the idea of simpler diagrams seemed a good one.

The diagrams

Most of the representations in the Boohan/Ogborn diagrams were quite good and could be readily adapted. However, it was felt that some simple rules and a classification system were needed. Ten forms of energy were decided upon and they were divided into two groups:

Energy transfers

- Kinetic
- Heating
- Radiation
- Electrical work
- Sound

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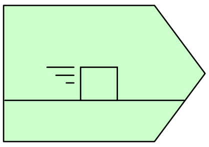
Potential energies

- Nuclear
- Internal
- Chemical
- Elastic potential
- Gravitational potential

The names should not be too similar, e.g. no heat and heating. They should not be confused with alternative sources, e.g. wave or solar, and they should not be too far from other accepted forms [4–6]. Already there is a problem: kinetic energy should be in the potential group. The transfer of kinetic energy is mechanical work. Kinetic energy is stored energy; think of a flywheel or a brick moving through space. The kinetic energy is stored 'in' the brick and isn't transferred until the brick does some work. As mechanical work doesn't usually enter into 11–14 curricula it was decided to leave that as it was initially and to sort it out later.

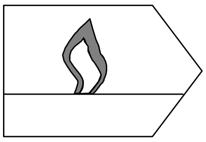
The next stage was to decide on the diagrams and definitions.

Energy transfers



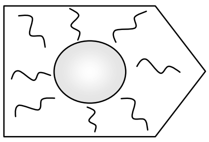
Kinetic

- Things that are moving have this form of energy.



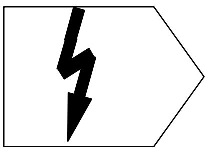
Heating

- This is how things get hotter.



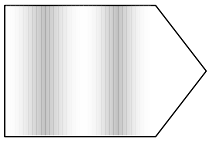
Radiation

- Light bulbs and the Sun give out this form of energy.



Electrical work

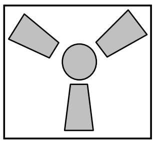
- This form of energy is provided by an electric current.



Sound

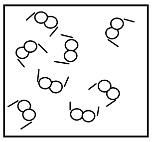
- This form of energy is noisy.

Potential energies[1]



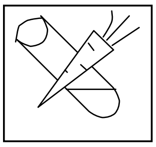
Nuclear

- The Sun, stars and atomic bombs use this form of stored energy.



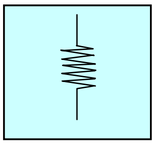
Internal

- Things that are heated store more of this sort of energy



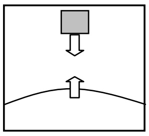
Chemical

- This is the energy that is stored in food and fuel.



Elastic potential

- If something is squashed or stretched it has this form of energy stored in it.



Gravitational potential

- Anything that is in a position where it could fall has this form of stored energy.

[1] Referee's comment: the following definitions are more strictly correct:

Nuclear: atomic bombs and stars, including the Sun, use this form of energy.

Internal: things that are at a higher temperature store more of this energy.

Elastic potential: something temporarily stretched or squashed has this form of energy stored in it.

Basics of the approach

Diagrams are good because we learn so much visually. The diagrams are printed onto coloured card. Potential energy cards were blue, energy transfers were green and transformers (more about these later) were yellow. There were also some arrows with numbers and percentages on, which are mentioned later. The tendency is to look at the energy in and out and not worry about the bit in the middle, as put forward by Robin Millar [7]. However, because of the nature of the method this doesn't mean a loss of detail.

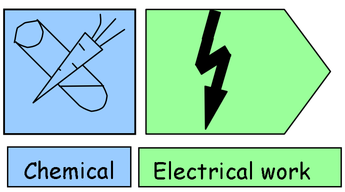
The lessons

The first stage in the lessons is to give each pair or individual a set of the diagram cards with the name cards and ask them to put the right name to the right card. This is more a measure of how good the diagrams are than anything else. 80% or more of the class will get them all correct. The next stage is to introduce the definitions. These are designed to be pupil-friendly and hence are simple. There are certain wordings that are not rigorous but we use for simplicity.

Using PowerPoint we go through the definitions. Pupils see the definition first then hold up the card they think matches the definition. This proves to be reasonably successful but highlights some problems, e.g. heating and internal energy and also chemical and internal energy. We discuss these but don't dwell on them; they will largely be ironed out later.

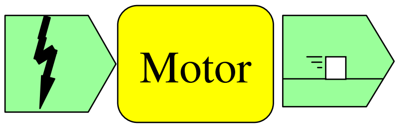
Next we introduce sources of energy. All sources need a form of stored or potential energy and a means of delivering the energy—a transfer. Thus all sources should consist of a square (blue) card followed by a pointed (green) card. The next step is to try some of the usual suspects, so we do:

A battery or cell



We then follow that with a coal- or oil- or gas-fired power station; the fact that the two are the same surprises the pupils. We go through several sources, the main reason for inclusion being that they may be useful later.

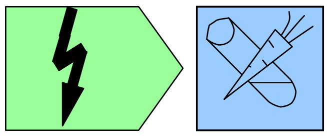
The next stage is to introduce transformers—things that change the form of energy without storing it. The examples we choose are quite restricted at first. Transformers are represented by a yellow rounded rectangular box.



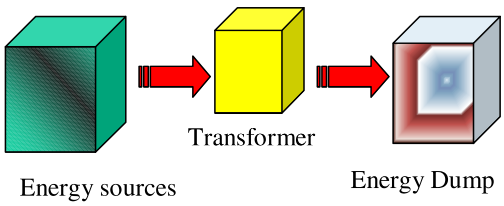
All tranformers have (green) pointed energy transfer boxes going in and out. We go through some other examples: loudspeaker, microphone, solar cell, lamp etc.

The next stage before things really start going is to discuss where the energy goes. The law of conservation of energy is inherent in the way the cards work; it can be introduced formally at any point. It starts to drift in here although we don't define it until later.

Energy dumps are where the energy goes and often it ends up going into the environment, but we also look at other examples such as lifting a mass and a cell charging.



Finally we start to string the separate bits together:

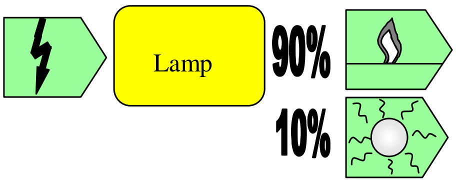


We go through the whole chain (but not the whole story) for a stereo:

In terms of class time it has taken a lot to get this far, probably some six hours of teaching time, but the end results seem to prove worthwhile. We can now introduce a number of situations and the pupils will be able to arrive at a chain like the one above.

But don't light bulbs get hot?

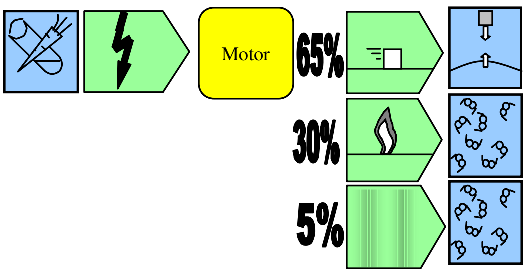
Usually someone has mentioned this already and the teacher can flag it up as a point to be looked at later. The problem we have so far is that we only have one form of energy emerging. This is unrealistic. Now is a good time to introduce the law of conservation of energy formally. A demonstration with a large heavy pendulum can be used to make the point but the method is not important. Next we introduce the idea of efficiency—a light bulb is roughly only 10% efficient. We discuss what this means—only 10% of the energy in goes where you want it. This leads to an energy transformer that looks like this:



The next stage is to give the pupils a chance: so they get this situation:

A cell drives a motor that is 65% efficient.
It loses 30% as heat and the rest as sound.
The motor lifts a mass.

Hopefully they produce something like this:



Look familiar? We are now heading towards the next stage, which is the introduction of a Sankey diagram. For 11–14 year-old pupils we leave it here—we can look at application to different situations rather than more advanced ideas; 14–16 year-olds go on to look at the Sankey diagrams and discuss the classification:

- Why kinetic energy may be in the wrong place.
- What mechanical work is.
- How internal energy can be thought of as kinetic energy.

We can also look at the forms in more detail:

- Heating and thermal energy transfer—conduction, convection and radiation.
- Radiation—what light is and its part in thermal energy transfer.
- Heating and internal energy—specific thermal capacity.

And so on.

Conclusion

No system is perfect but this one does work well. It starts off slowly but most pupils seem to get a good grasp of the subject matter and produce far more complicated energy chains than they may have ever achieved by other methods. It has had the same good response throughout the ranges of age and ability *except* for the very lowest ability classes—it was found that the whole thing was too abstract for them. They were not able to grasp the fact that the cards represented something. They had no grasp of such a concept and so the cards and labels seemed to have little connection to any logic.

It is hoped that other teachers will give this method a try and give their opinion on it. The PowerPoint slides and all the files with the cards on etc can be downloaded from the electronic version of this journal.

Teacher notes

These are just our thoughts and opinions as we have used the resources in the classroom.

Gary Williams:

I always feel unsure at the start, like it isn't working. This disappears after a couple of lessons when the pupils start getting quite complicated things right. I like to get something into their books so they can refer back to it. Drawing can take a while but the symbols are pretty easy to copy—I did wonder about having a template made that matched the shape of the boxes. Last time I taught this I photocopied the symbols onto green and blue paper and the pupils cut out the relevant bits and stuck them in their books. This took longer than anticipated but it did make the books look good!

I think more pictures might make the situations more realistic—like a picture of someone filling a car at the petrol station and driving it, and some well thought-out bits of apparatus for the pupils to try and analyse would be good.

The thing I've noticed most is really the point made by Ogborn and Boohan in [8]. The cards give the pupils something to talk about. They rarely get things wrong because when we discuss why they think a particular outcome is true as opposed to the outcome favoured by others, it usually transpires that they've made a different set of assumptions.

Tony Reeves:

> *It is important to realise that in physics today, we have no knowledge of what energy* ***is****.*
>
> R P Feynman

Who are we to argue with Feynman? Does a study of energy and energy transfer justify its inclusion in the 11–16 National Curriculum? Energy is a notoriously difficult topic to do justice to. Much of it comes down to taxonomy and semantics as far as the pupils are concerned. There is a real temptation for teachers and examiners to take refuge in the relatively safe zone of energy calculations and to concentrate on those forms of energy that can readily be quantified—this has inevitable repercussions for lower ability students. I was interested to see what the energy card approach had to offer in terms of my lower ability Year 9 set.

After a brief introduction to the energy card approach and a follow-up discussion with Gary I felt confident enough to give the system a trial run. The class took to the cards readily. The identification of symbols got them 'on task' quickly and they were eager to offer comments as to the suitability of the various symbols. A suitable homework for the future will be to design an improved version of some of the cards.

A cut-and-paste session provided them with an opportunity to get a neat version of the basic diagrams and nomenclature into their books.

In the following lesson, having located the 'transformer' cards (also known as 'transducers') in their zip-lock bag, some of the pupils were already shuffling cards into appropriate sequences. They were invited to assemble appropriate sequences for each of the transformers with a good deal of success, an element of competition and peer learning adding to the value of the exercise. This exercise was again reinforced by a cut-and-paste session—the use of coloured paper to match the cards making for an attractive effect in their exercise books.

At this stage the energy sequences were fairly straightforward (avoiding the 'potential energy' cards). In the past I have opened the energy topic with a 'circus' of energy conversions—this was introduced at this stage. Out came the toy boats, windmills and jumping frogs—good fun made more meaningful by the requirement that at each station the pupils were obliged to arrange the energy cards appropriately. There was much debate about the 'best' cards to use and it was apparent that a number of alternatives were equally 'correct'.

It was out of logistic considerations that the PowerPoint presentation came last in the sequence (I lost the earlier battle for the data projector) but in the event this proved to have its merits. The class were very content that they 'knew' the 'right' answers before the labels arrived and that their knowledge was being confirmed and reinforced by the computer. The finale of the PowerPoint presentation invites the pupils to identify the energy sequence associated with a solar cell driving an electric motor. There were very few 'failures' but there were varying degrees of success and a good sense of achievement.

So, what does the energy card approach offer and should you be tempted to give it a try? I think that it certainly gets pupils onto task quickly. It increases 'thinking time' by reducing the reliance on 'notes'. The cards along with the PowerPoint presentation (or OHP acetates) offer a very flexible resource which can be combined with your currently favoured approach. If you don't like some of the terminology or diagrams then the cards can be customized to suit your preferences. There is plenty of scope for further development and I plan to introduce symbols with targets and dustbins on them that can be placed on energy that 'goes where we want it to' and 'wasted energy'. The acid test is that I enjoyed these lessons and that I believe that the pupils got something valuable from them. If nothing else, considering a new approach will force you to reappraise your own thinking about energy.

Acknowledgments

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References

[1] Goldring H and Osborne J 1994 Students' difficulties with energy and related concepts *Phys. Educ.* **29** 26
[2] McIldowie E 1995 Energy transfer—where did we go wrong? *Phys. Educ.* **30** 228
[3] Shayer M and Adey P 1981 *Towards a Science of Science Teaching* (London: Heinemann)
[4] Rogers E and Wenham E (ed) 1978 *Revised Nuffield Physics Teachers' Guide, Year 4* (London: Longman)
[5] Nelkon M and Deheridge M 1987 *GCSE Physics* (London: Pan)
[6] http://ucsbuxa.ucsb.edu/es/es115/overheads.html
[7] Britton P 2001 Naming the energy parts [News item] *Phys. Educ.* **36** 361
[8] Boohan R and Ogborn J 1996 Differences, energy and change: a simple approach through pictures *Sch. Sci. Rev.* **78** (283) 17

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