Secondary Science

Probing understanding: work and energy

Teacher Education through School-based Support in India
www.TESS-India.edu.in

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Some of the activities in this unit are accompanied by the following icon: . This indicates that you will find it helpful to view the TESS-India video resources for the specified pedagogic theme.

The TESS-India video resources illustrate key pedagogic techniques in a range of classroom contexts in India. We hope they will inspire you to experiment with similar practices. They are intended to complement and enhance your experience of working through the text-based units, but are not integral to them should you be unable to access them.

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Version 2.0 SS09v1
All India - English

What this unit is about

There are some topics in science that many students find difficult. It is possible for students to hold ideas about a topic that a teacher would consider to be 'wrong'. This does not necessarily stop students memorising work in the short term, or getting the answers to questions correct. However, it does make it difficult for them to develop the sort of deep understanding they need to remember a large amount of material and do well in examinations. It will also be difficult for your students to progress if they continue to hold these ideas. Over the years, as a result of research, people have built up a list of common misunderstandings for many topics.

As a teacher you will need to help students to undertake conceptual change – some form of restructuring of what has been previously learned. Your role is to make the new approach seem more logical, coherent and sensible so that, in time, it becomes the student's preferred way of thinking and they no longer use their initial ideas. In this unit the focus will be on work and energy, which is a difficult concept for students (and some adults) to understand properly. The strategies and techniques that you will learn in this unit will apply to other topics as well.

What you can learn in this unit

- Some of the misunderstandings that students hold about energy and work.
- How to find out about your students' understanding of energy and work.
- Some ways of helping your students to undertake conceptual development and achieve a better understanding of energy and work.

Why this approach is important

Students can have ideas and conceptual frameworks about any topic that are different to accepted scientific thinking. Even so, they may still be able to correctly answer questions that they have been asked. However, in the longer term, these 'wrong' ideas will be a problem, and will stop students from making progress. Teachers need to find out what their students actually think if they are to help them progress. Teachers also need to find ways of challenging unhelpful ideas and replacing them with something more useful. It is well known (Driver et al, 1994) that students can memorise new ideas in the short term, but if they don't fully understand the new ideas, then in the longer term they will go back to their own ideas, which might not be completely correct. Students can be very tenacious in holding onto ideas they bring to lessons from their prior experience. Active learning is needed to bring about conceptual development (making new ideas and frameworks available to the student). The student must engage in mental activity as they explore new ideas and their relationships with other concepts.

For example, many students may confuse energy with fuel, and they may describe energy as being 'used up' in various situations. They may, for example, correctly predict that a ball released on a u-shaped track should not reach any higher than the height from which it was released, but will say this was because 'all the energy has been used up'. As they move to higher classes, they will not be able to make progress in physics if they think of energy as being 'used up': they need to understand that it is conserved and can only be converted from one form to another.

1 Some common misunderstandings about energy

When students try to make sense of a new situation, they draw on everyday experience and on ideas that have worked well for them before. Teachers may recognise some of these ideas as 'not scientific' or 'not the accepted explanation'. But as long as these ideas are able to predict what will happen, then students will use them.

These 'misunderstandings' are not like equations or definitions that have been learnt incorrectly. Misunderstandings can be the result of explanations that students have been given by other people (sometimes a much-loved and respected relative or teacher). Sometimes they are explanations that the student has constructed for themselves. Alternatively, these explanations were appropriate for earlier classes but are no longer relevant for more complex ideas and topics.

There is often a lot of 'common sense' appeal about these ideas, but the problem is that using them is going to be unhelpful in work in secondary school science. These ideas can act as a barrier to understanding the accepted models of science.

For example, many people think that insulation 'makes things warm' because they have observed that wearing thick clothing on a cool evening makes them feel warmer. This could lead to an incorrect prediction as in this situation:

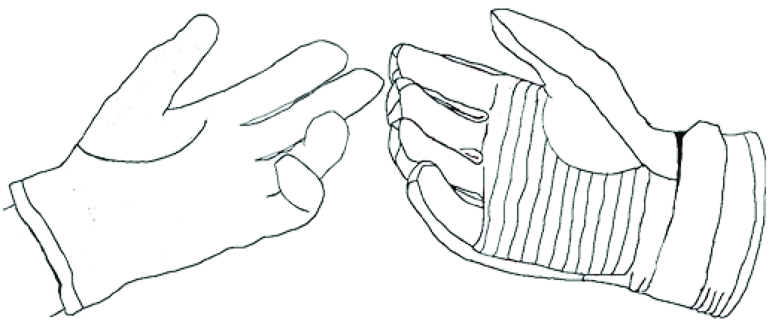

Figure 1 A thin glove and a thick glove. Which is warmer on the outside surface?

- **Incorrect prediction:** The sensor placed on the outside of the thick glove (see Figure 1) will show a higher temperature than the one on the thin glove because a thick glove will make the hand warmer. Thick gloves are warmer so the surface of the glove will be at a higher temperature.
- **Correct prediction:** The sensor placed on the thick glove will show a lower temperature because the thick glove slows down the transfer of energy from the warm hand to the cold surroundings more than the thin one does. The outside of the thick glove will still be relatively cool.

Case Study 1: Misunderstandings about energy

Mr Gupta attended a training session at the local DIET. Instead of sitting and listening to the trainer, the group members were asked to take part in a number of activities.

Last week I attended a training session about common misunderstandings in science. The trainer started by asking us to work in groups of three, where one of us was a physics specialist, one a chemistry specialist, and another a biology specialist. The trainer gave us three questions to consider, one about each subject. We had to think about each question on our own and then share our ideas, with the subject specialist listening to the others before offering their ideas.

The physics question we had to think about was: 'A spacecraft is going to be sent out on a long voyage beyond our solar system. It has a powerful rocket engine with large fuel tanks. Why does it need a lot of fuel and what will happen when the fuel is used up?' I'm a biology specialist, and it was interesting (and a bit scary) to share ideas about this! I said that you would need fuel to get away from Earth and propel the spacecraft over the huge distance it would need to travel. Once the fuel was used up, the spacecraft would slow down and stop, so if there wasn't enough fuel it might be stranded in the middle of space.

My physics colleague explained that the large fuel tanks were needed for the launch stage to break away from the Earth, and that some relatively small motors are needed for the main part of the voyage. In deep space there is no air resistance or strong gravitational pull to overcome, so a spacecraft does not need fuel to keep it at a steady chosen velocity – only to change speed or direction.

I felt a bit embarrassed when I realised my misunderstanding, but the trainer told us that lots of people have the same idea as I had. It was a relief when she told us this and also when the physics teacher had difficulty with the biology question about plants, food and photosynthesis. Neither of us was stupid; it was just that we were trying to explain something unfamiliar using models based on everyday experiences, and we needed to use accepted models of science to correctly explain what happened.

Pause for thought

- What answer would you have given to the 'spacecraft' question, and why?
- Can you think of any misunderstandings that you have noticed your students have shown in the 'energy and work' topic?

You can find some more examples of common misunderstandings about energy in Resource 1.

Everyone has misunderstandings of science topics, or understandings that are different to the scientific models in the curriculum. You may find it surprising that teachers can have misunderstandings about their own specialist subject, too! They often only realise this when they see a question about something that they haven't studied or taught before, or if an idea is presented in an unusual, unfamiliar context.

Although this can seem embarrassing, a good teacher will appreciate that they have learnt something important and improved their own understanding. It will also help them to be aware of the potential problem for students, and plan to identify and deal with it.

Activity 1: Common misunderstandings in your students' work

This activity will help you to plan for teaching about work and energy. You will need Resource 1 for this activity, plus a set of sticky note labels.

Read through the list of common misunderstandings in Resource 1. Which of these have you met before in your students' work on this topic?

Now read through the Class IX textbook chapter on work and energy. As you read, look for any misunderstandings in Resource 1 that might be relevant to the chapter. Every time you identify a possible misconception, write it down on a sticky label and put it next to the relevant section of the textbook. You may find that some possible misunderstandings are relevant several times, while others don't seem so likely to be relevant. Do not worry about finding a match for every section or for every misunderstanding! The purpose of this activity is to alert you to some of the common misunderstandings, so you can be ready to notice them when they occur. It is much easier to recognise something when you know what you are looking for!

In the next section you will learn about ways of probing your students' understanding. The techniques described here work for any topic area. The key resource 'Assessing progress and performance' (http://tinyurl.com/kr-assessingprogress) will also be helpful.

Video: Assessing progress and performance

http://tinyurl.com/video-assessingprogress

2 Finding out about your students' understanding of work and energy

How can you find out about your students' understanding of work and energy? If they are able to get all the right answers for calculation questions, you might assume that they have good understanding. However, students can hold misunderstandings about work and energy but carry out calculations correctly. The rules they have applied to carry out the calculation do not rely on understanding of the underlying physics.

For example, suppose you ask a student to calculate the potential energy gained by raising an object of mass m through a height h. They know that $Ep = mgh$, so if you give them values for m, g and h they can do the calculation. However, they may be unable to explain what happens when the load is released and falls to the ground in terms of energy transfer and energy conservation.

They may say that the load had potential energy when raised, that it had kinetic energy when it was falling, and that when the load landed its energy had somehow 'gone'. It may take some further questioning to find out what might have happened to this 'missing energy' if energy is conserved.

There are some simple strategies that you can use to probe your students' understanding of work and energy. What all these strategies have in common is that they encourage students to share their ideas with you and with other students. This is very important, as existing knowledge and understanding act as foundations for new learning.

Useful strategies to find out about students' understanding include focused questioning, group discussion and poster presentations, as well as the following approaches, which may be less familiar:

- **'Predict and explain':** Give students a situation and ask them to predict what will happen next *and* explain their prediction.
- **'True/false/unsure' card sort:** Give each pair or group of students a set of cards, each of which has a single statement about energy and work. Students sort the cards into separate piles for 'true', 'false' and 'unsure'.
- **'Traffic lights':** Each group of students shows their decision about a statement by holding up a green (true), red (false) or yellow (unsure) voting card
- **Concept cartoons:** Cartoons that show a situation with two or three statements about what is happening. Students have to decide which statement(s) they agree or disagree with, and say why.
- **Annotated diagrams:** Ask students to annotate an image or diagram of a system or a situation, using ideas about energy and work

You can find examples for each of these in Resource 2.

Case Study 2: Showing understanding in a classroom activity

Miss Bulsara tries out some strategies for probing her students' understanding of work and energy.

Whenever I have taught work and energy to my Class IX, they always seem to manage to do the calculations, but often seem to make mistakes in questions where they have to describe or explain something. Perhaps if I knew what my students found confusing, I could help them!

This year, I decided to try to find out more about what my Class IX students don't understand about work and energy. I didn't want anyone to spend a lot of time on drawing or writing things out neatly, so I decided to use two of the concept cartoons we had been shown at a training session. [These are the cartoons in Resource 2.] Students like hearing someone else's opinion and making a judgement about it, and I like the idea of using concept cartoons, because they encourage students to consider different possibilities before they answer.

First of all, I divided my students into groups of three or four students, and gave each group the two concept cartoons. I told them that they had five minutes to discuss each of the two cartoons in their group and decide what the best answer in each case was. I gave each group two decision cards, one with a large A on it (for 'answer A is better') and one with a large B on it.

I walked round the classroom and listened to the discussions. Sometimes they were quite lively, but I could tell that my students were interested in the discussion.

I stopped the discussions after ten minutes and told my students to choose one person from each group to report on their decisions. I stood at the front of the room with everyone facing me, and asked the group representatives to show me their chosen decision cards at the same time, so I would be the only one who could see what all the decisions were. Not every group had agreed with what I thought was the best answer, but the other groups didn't know that.

I asked someone from one of the groups that had chosen what I thought was the best answer to explain how they had decided. I wanted to encourage them to share ideas with the whole class without being embarrassed, so I praised the way they had offered the explanation, and said that when I was walking round, I'd been impressed by the discussions going on in all of the groups. When all the groups had voted on the second cartoon, I asked someone from another group to explain how they had made their decision, again making sure they had chosen what I thought was the best answer. My students wanted to know what I thought was the best answer and why, so we spent another five minutes talking about the cartoons.

Listening to my students helped me to plan my next lesson with them. Now I know much more about their existing understanding I can set up situations to introduce them to accepted scientific concepts.

Video: Monitoring and giving feedback

http://tinyurl.com/video-monitoringandfeedback

Activity 2: Testing students' knowledge of 'work' in class

This activity will help you to develop your in-class practice. You are going to use one of the strategies described in Resource 2 to look at your students' understanding of work and energy. (This activity is based on Activities 11.2 and 11.3 in the Class IX textbook (the National Council of Education and Training version).)

- Ask your students to think of situations from their daily lives that involve 'work'. In each case, ask them to say how work is being done, and explain why they think that. You can treat this as an example of the 'predict and explain' approach. (Before the lesson, identify three or four examples of situations that you would like groups to consider. Make a note to yourself of what decision you would like and what you would like them to include in their explanation. Resource 3 will be helpful for this.)
- Ask them to think about a situation in which an object is not displaced, even though a force acts on it.
- Ask them to think about a situation in which an object gets displaced in the absence of a force acting on it.
- Circulate as the groups discuss the different situations. Unobtrusively, make a note of what predictions each group makes and what reasons they give.
- Discuss the answers that you hoped for with your students, explaining the reason for each prediction.
- After the lesson, think about these questions:
  - What were the most difficult situations for students to decide about?
  - Which situations did most groups get right in terms of the prediction and the explanation?
  - Which situations did most groups get wrong? What kinds of reasons were the groups giving in these situations?

Pause for thought

- Were you surprised by any of the answers the groups gave?
- Were there any common misunderstandings in your students' incorrect explanations?

Figure 2 While your students are working, walk round and listen carefully to what they are talking about. If necessary, prompt them with questions, but don't be tempted to tell them the answers.

3 Helping your students to achieve a better understanding of energy and work

When a student has a misunderstanding that seems to explain an idea, they will only give it up if you can show them that another way of explaining the idea works better. Sometimes students will partially accept the 'new, improved' model, but create another 'hybrid' model of their own, or may switch between models depending on the situation.

There is no single solution to the problem, but research and common experience suggest that the following strategies help:

- Give students opportunities to discuss their ideas with other students in a supportive environment.
- Ask students to use their model to predict what will happen in different situations, and identify situations where their current model does not work but an accepted scientific model does. Discuss the differences between these models.
- Continue to present opportunities for students to challenge and refine their ideas.

Carefully structured practical experiences and demonstrations can be an effective way of providing evidence to challenge a misunderstanding. They don't have to be big, spectacular experiments with lots of equipment: sometimes quick, low-key demonstrations and practical experiences can provide what is needed. Whatever you do, the important points to remember are that:

- the practical experience is there to support the development of ideas, so you must be clear about what you will need to draw their attention to
- you check the practical experience beforehand exactly as you intend it to be done, to make sure that students will be able to experience what you intend them to experience.

Activity 3: Learning about energy

This activity will help you to develop your in-class practice by using a practical activity with focused questioning to direct your students' attention. (This demonstration is based on Activity 11.6 in the Class IX textbook and is one of several related to kinetic energy.) The purpose of the demonstration is to emphasise that energy is not 'used up', just converted from one form into another.

Drop a ball from an increasing height into a tray of wet sand. Start at a height of 25 cm and repeat from heights of 50 cm, 1 m and 1.5 m. Your students should notice that dropping the ball from an increasing height results in deeper impact craters.

You might use the following sequence of questions, or similar. The point of the questioning is to track the energy. The questions are in bold and the responses are in plain text.

- **Which needs most energy to make it – a deep crater or a shallow one? Why?** Students should say the deep crater, and may say that digging a deep hole takes more work than digging a shallow one.
- **What provided the energy in this case?** The ball. The ball's energy is transferred to the sand.
- **Is the ball doing work on the sand, then? Explain.** Yes, because it is making the sand move.
- **What does the crater depth tell you about the energy supplied by the ball when dropped from an increasing height?** The ball supplies more energy to the sand when it has been dropped from a greater height.
- **So, which ball had most energy as it hit the sand?** The one that made the deepest crater.

- **So, which ball must have had most energy before it was dropped?** The one that was dropped from the greatest height.
- **So, what can you say about the energy of the ball when it has landed in the sand?** The energy has been transferred to the sand. (This is the key point for making the connection. Some students may say it has 'gone'. If they do, ask them where it has gone.)

Now you need to pull all of this together by asking students to give a description of the whole sequence, not just piece by piece:

- **To recap, tell me about the ball's energy from when it is raised, then as it drops, then as it lands: what can you tell me about the amount of energy it has?** The ball gains more (potential) energy the higher it is lifted. As it falls, the ball gets faster – so we can say it has more kinetic energy the faster it falls, but it doesn't have more energy overall (because it has less potential energy). When the ball has landed in the sand, it has lost all the energy you gave to it by lifting it up; it must have lost all the kinetic energy it had just before it hit the sand, because we can see it has stopped.
- **Where did all that the energy go?** It was transferred to the sand to move it. Or, to put it another way: it was used to do work on the sand.

If you have a very large class, you could do the demonstration to smaller groups, while the rest get on with some work from the textbook. By planning the questions carefully in advance, you will be able to make good use of the demonstration. Of course, they might not respond as you expect, but if you are clear about the purpose of the demonstration, it will be easier for you to react to what they say.

Careful questioning is a very good way to find out what your students are thinking. To find out more about using questioning in your classroom read Resource 4.

Video: Using questioning to promote thinking

http://tinyurl.com/video-usingquestioning

4 Summary

In this unit you have learnt about some of the misunderstandings that students have and some strategies for finding out more about your students' understanding. You have also had an opportunity to use a strategy to help improve your students' understanding.

None of the strategies described in Resource 2 need specialist practical resources or take up a lot of time in class. Why not try using the concept cartoons or a card sort when you are teaching this topic, or when students are revising? 'Traffic lights' can also be a useful technique whenever you want to gauge understanding quickly.

Resource 5 provides a set of statements about energy. The statements are accompanied by answers and comments. You could use these statements to explore your own understanding as described in Case Study 1, but you can also use this resource to help you identify possible points of difficulty for your students.

Although this unit has focused on energy, work and force, students will have alternative models and frameworks in other areas of the science curriculum. You can adapt the techniques in Resource 3 to use with other topics. This will be easier if you work with other teachers and share resources and experiences.

Resources

Resource 1: Some common misunderstandings about energy

This resource is for use with Activity 1.

- Energy can be used up.
- Objects only have energy when they are moving.
- Objects keep moving until the energy is 'used up'.
- Energy is often lost in energy transfers.
- Energy is a substance.
- Energy is fuel.
- Force is the same as energy.
- Force is the same as work.
- Biological processes, such as photosynthesis or respiration, produce energy.
- Some objects/materials are naturally warmer than others.

Resource 2: Some ways of eliciting your students' ideas about energy and work

There are a several strategies – such as focused questioning, group discussions and poster presentations – that you might use in order to find out what prior ideas students have and the misunderstandings that students may hold.

Below are some other examples, with comments. The key point about using any of these strategies is to encourage students to share their ideas with you and with other students: the discussion that goes into producing a diagram is more important than having a neat or colourful diagram with impressive artwork!

Predict and explain

Give students a simple scenario and ask them to say what will happen next and why they think that. As an example, consider a ball on a U-shaped track (Figure R2.1).

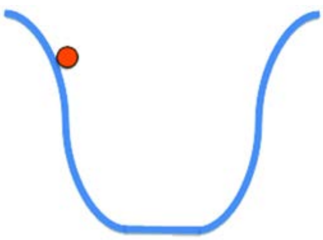

Figure R2.1 A ball on a U-shaped track.

Predict what will happen when the ball is released. Explain your answer.

Comment

Many students will be able to make a correct prediction about what will happen to a ball on a U-shaped track, but fewer of them will be able to explain this prediction correctly in terms of energy conservation and transfer.

The ball should roll down the track and up the other side until it is at the same height as it was released from: the higher the ball is, the more potential energy it has, so the highest point it can climb to will have the same potential energy as it started with. The ball loses potential energy as it falls, but gains kinetic energy, so it is moving fastest (i.e. using the most kinetic energy) at the bottom of the curve, where it has the least potential energy.

The ball should continue rolling up and down the track indefinitely and reaching the same maximum height each time, if (and only if) there is no energy transferred to its surroundings due to air resistance or friction with the track. If energy is transferred to the surroundings, then each time the ball climbs up the track, it will climb to a slightly lower level than before. Its maximum potential energy will be less each time and it will eventually settle to a stop at the bottom of the curve.

It is important to ask for a prediction and an explanation. In an unfamiliar situation, students have to draw on their scientific understanding to make a prediction. But if you use a situation that students have met before, they may be able to make a correct prediction based on memory rather than understanding. Unless you ask for an explanation as well as a prediction, it may not be obvious that your students do not understand the underlying science.

Card sorts ('True/false/unsure' card sort)

Prepare a set of cards for a topic. Each card has a short statement on it such as 'Using a lever saves you energy'. Students must decide if each statement is true or false, or if they are not sure. They should sort the cards into separate groups for each category. It is helpful to include pairs or groups of related statements in the set of cards you provide, to help pick out where the misconception may be. For example:

- 'Using a lever makes it easier to lift something heavy because saves you energy.'
- 'Using a lever makes it easier to lift something heavy because it lets you use a smaller force.'

Comment

Card sorts let you see very quickly what ideas students have as you walk round the classroom. They are also a 'low threat' activity, since there is no permanent record of choices.

'Traffic Lights'

The 'Traffic Lights' game is similar to a true/false/unsure card sort. The activity still uses a set of statements and students must still decide if they agree or disagree with a statement, or if they are unsure about it. Instead of physically sorting statements into three groups on different parts of the table, students must respond to each statement that you read out or show them by holding up a response card. The 'Traffic Lights' are the three different cards they can hold up:

- green (true/agree)
- red (false/disagree)
- yellow or amber (not sure).

You can have all the statements written up on the blackboard for groups to discuss before you ask them to vote.

Comment

'Traffic Lights' let you see very quickly what ideas students have, and whether there are ideas that many or only a few find confusing. It is also a 'low threat' activity, since there is no permanent record of choices.

Concept cartoons

Two examples of concept cartoons are shown below. You could show Figure R2.2 to a class and ask, 'What do you think?'

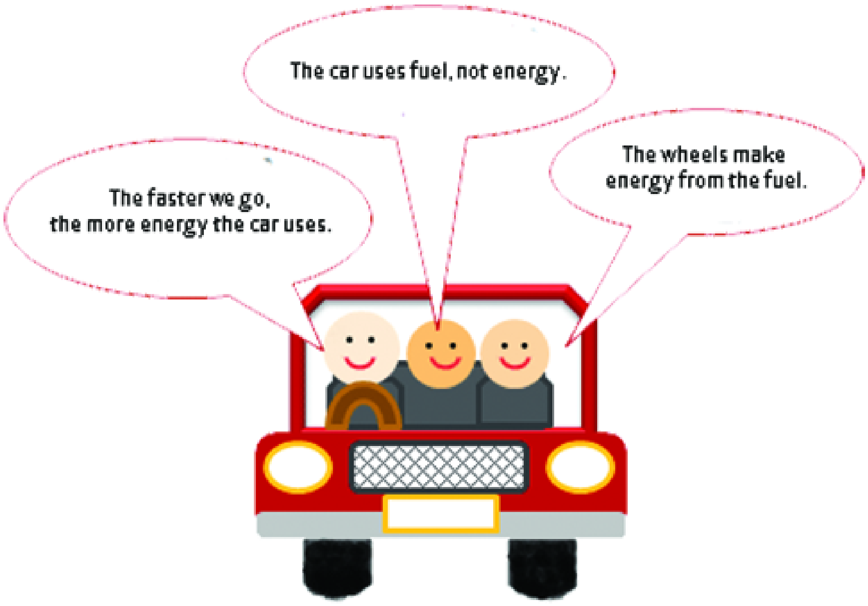

Figure R2.2 An example of a concept cartoon.

You could show Figure R2.3 to a class and read the following statements:

- Statement A: 'It is easier to lift the load using a two-pulley system compared to just a single pulley. Pulleys save you energy!'
- Statement B: 'The two-pulley system lets you lift the load with a smaller force, but it does not save you energy.'

Then ask your students what they think.

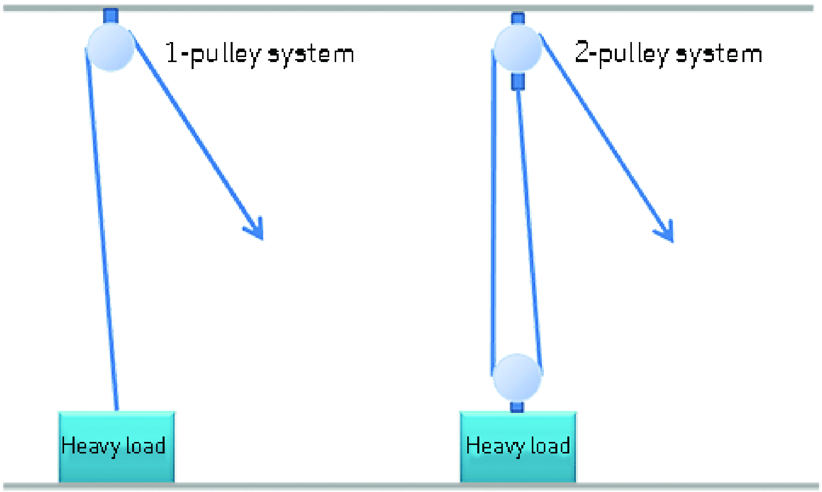

Figure R2.3 An example of a concept cartoon.

Comment

This could be a homework activity for individuals, or a group or individual activity in class. The annotations should be your students' own explanations or descriptions. They should stick to the brief and not wander off into 'borrowing' a set of labels from a textbook or the internet.

Resource 3: Identifying work done in various activities

The mental model that students need in order to be able to answer questions about energy and work is that doing work involves moving a force over a distance. If something is being lifted up, then the force is the weight of the object, the distance is the height it is lifted and work is being done on that object.

If something is being pushed or pulled along and is not being lifted up, then the force is likely to be friction, and the distance will be the distance over which the force is acting. Some of the situations that students will choose are actually quite complicated. For example, if you walk along a flat road, you are clearly doing work, but the 'force' will not be your weight.

Suggested activities for Activity 2 are listed in Table R3.1.

Table R3.1 Suggested activities for Activity 2.

Activity	Comment
Lifting the kettle to make tea	Work is done on the kettle. The force is the weight of the kettle and the displacement is the height to which it is raised.
Walking to school	Technically, if the walk to school is flat, then work has not been done: the force (weight of the student) has not moved. However, walking to school clearly tires you out. The work is not being done to the 'centre of mass' of the object in the same way as lifting a kettle does work on the kettle. In this case, the work is being done in many small parts – lifting the feet, pushing against friction, etc.
Cycling to school	Again, if the cycle to school is flat, then work is not being done on the 'centre of mass' of the student. But work is being done by pushing against the pedals
Lifting a bag of books on to the desk	Work is done on the bag of books. The force is the weight of the bag and the displacement is the distance it is lifted.
Writing in an exercise book	The force in this case is in overcoming friction. The displacement is the distance over which the force is applied.
Kicking a football	If the ball is kicked up in the air, then the force is the weight of the ball and the displacement is the height it goes to.
Running to catch a bus	Technically, when running on flat ground, no work is done to the centre of mass of the object (student). But running involves lifting the feet. Running involves more 'work' than walking, because the feet are lifted higher. A slow motion film of a runner might actually show them to be off the ground completely at some point. Running or walking uphill involves doing work on the centre of mass of the walker or runner.

Activities that involve a force being applied, but no movement, include leaning on a post or trying to push a large boulder. Technically speaking, according to the mental model that students are being encouraged to use, no work is being done in these cases. But if you are pushing a large object, then clearly you get tired! The 'work' is at a smaller level – the movement of your muscles and bones.

Objects being moved with no obvious force being applied would include a ball moving through the air or a spaceship travelling in space. If no force is being applied, then no work is being done. For a ball travelling through the air, forces are being applied: air resistance and gravity. The ball will slow down and stop, so work is being done on the ball. For a spaceship, there is no air resistance or gravity, so it will keep moving in a straight line unless a force is applied to it.

Resource 4: Using questioning to promote thinking

Teachers question their students all the time; questions mean that teachers can help their students to learn, and learn more. On average, a teacher spends one-third of their time questioning students in one study (Hastings, 2003). Of the questions posed, 60 per cent recalled facts and 20 per cent were procedural (Hattie, 2012), with most answers being either right or wrong. But does simply asking questions that are either right or wrong promote learning?

There are many different types of questions that students can be asked. The responses and outcomes that the teacher wants dictates the type of question that the teacher should utilise. Teachers generally ask students questions in order to:

- guide students toward understanding when a new topic or material is introduced
- push students to do a greater share of their thinking
- remediate an error
- stretch students
- check for understanding.

Questioning is generally used to find out what students know, so it is important in assessing their progress. Questions can also be used to inspire, extend students' thinking skills and develop enquiring minds. They can be divided into two broad categories:

- **Lower-order questions**, which involve the recall of facts and knowledge previously taught, often involving closed questions (a yes or no answer).
- **Higher-order questions**, which require more thinking. They may ask the students to put together information previously learnt to form an answer or to support an argument in a logical manner. Higher-order questions are often more open-ended.

Open-ended questions encourage students to think beyond textbook-based, literal answers, thus eliciting a range of responses. They also help the teacher to assess the students' understanding of content.

Encouraging students to respond

Many teachers allow less than one second before requiring a response to a question and therefore often answer the question themselves or rephrase the question (Hastings, 2003). The students only have time to react – they do not have time to think! If you wait for a few seconds before expecting answers, the students will have time to think. This has a positive effect on students' achievement. By waiting after posing a question, there is an increase in:

- the length of students' responses
- the number of students offering responses
- the frequency of students' questions
- the number of responses from less capable students
- positive interactions between students.

Your response matters

The more positively you receive all answers that are given, the more students will continue to think and try. There are many ways to ensure that wrong answers and misconceptions are corrected, and if one student has the wrong idea, you can be sure that many more have as well. You could try the following:

- Pick out the parts of the answers that are correct and ask the student in a supportive way to think a bit more about their answer. This encourages more active participation and helps your students to learn from their mistakes. The following comment shows how you might respond to an incorrect answer in a supportive way: 'You were right about evaporation forming clouds, but I think we need to explore a bit more about what you said about rain. Can anyone else offer some ideas?'
- Write on the blackboard all the answers that the students give, and then ask the students to think about them all. What answers do they think are right? What might have led to another answer being given? This gives you an opportunity to understand the way that your students are thinking and also gives your students an unthreatening way to correct any misconceptions that they may have.

Value all responses by listening carefully and asking the student to explain further. If you ask for further explanation for all answers, right or wrong, students will often correct any mistakes for themselves, you will develop a thinking classroom and you will really know what learning your students have done and how to proceed. If wrong answers result in humiliation or punishment, then your students will stop trying for fear of further embarrassment or ridicule.

Improving the quality of responses

It is important that you try to adopt a sequence of questioning that doesn't end with the right answer. Right answers should be rewarded with follow-up questions that extend the knowledge and provide students with an opportunity to engage with the teacher. You can do this by asking for:

- a *how* or a *why*
- another way to answer
- a better word
- evidence to substantiate an answer
- integration of a related skill
- application of the same skill or logic in a new setting.

Helping students to think more deeply about (and therefore improve the quality of) their answer is a crucial part of your role. The following skills will help students achieve more:

- **Prompting** requires appropriate hints to be given – ones that help students develop and improve their answers. You might first choose to say what is right in the answer and then offer information, further questions and other clues. ('So what would happen if you added a weight to the end of your paper aeroplane?')
- **Probing** is about trying to find out more, helping students to clarify what they are trying to say to improve a disorganised answer or one that is partly right. ('So what more can you tell me about how this fits together?')
- **Refocusing** is about building on correct answers to link students' knowledge to the knowledge that they have previously learnt. This broadens their understanding. ('What you have said is correct, but how does it link with what we were looking at last week in our local environment topic?')
- **Sequencing** questions means asking questions in an order designed to extend thinking. Questions should lead students to summarise, compare, explain or analyse. Prepare questions that stretch

students, but do not challenge them so far that they lose the meaning of the questions. ('Explain how you overcame your earlier problem. What difference did that make? What do you think you need to tackle next?')

- **Listening** enables you to not just look for the answer you are expecting, but to alert you to unusual or innovative answers that you may not have expected. It also shows that you value the students' thinking and therefore they are more likely to give thoughtful responses. Such answers could highlight misconceptions that need correcting, or they may show a new approach that you had not considered. ('I hadn't thought of that. Tell me more about why you think that way.')

As a teacher, you need to ask questions that inspire and challenge if you are to generate interesting and inventive answers from your students. You need to give them time to think and you will be amazed how much your students know and how well you can help them progress their learning.

Remember, questioning is not about what the teacher knows, but about what the students know. It is important to remember that you should never answer your own questions! After all, if the students know you will give them the answers after a few seconds of silence, what is their incentive to answer?

Resource 5: Understanding energy

Energy suffers from a problem. We often treat it as a real substance of some kind, but Richard Feynman, the Nobel Prize-winning physicist, had this to say about energy (Feynman et al, 1964):

> There is a fact, or if you wish a law, governing all natural phenomena that are known to date. There is no exception to this law – it is exact so far as is known. The law is called the conservation of energy. It says that there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.

Here are some ideas about energy that might be common. How would you respond to these ideas?

1. There is energy in food. When we eat food, the energy goes in to our bodies so that they can work.
2. Energy can come in different types. Some of these types are sound, light, chemical and kinetic.
3. When you drive a car, the energy in the petrol is used up, which is why you need to refill the car with petrol.
4. Energy can be stored in different ways, like in the chemicals in batteries or in an object that has a specific position in a gravitational or electric field.
5. Energy can be transferred from one place to another by a range of mechanisms such as electric current, sound and light.
6. Energy is not real. We should accept that it is a mathematical idea that helps us understand the world around us.

Which do you think are the most accurate statements from a physics point of view?

Answers

1. Energy is stored in the chemicals in food. This energy is transferred to our bodies so that they can function by using the energy in chemical reactions.

2. This is a common method of thinking, but in recent years teachers have been encouraged to think of energy as being in a single form that is transferred from one place to another through various pathways such as electric current, light and sound.
3. This is not good thinking. Energy is never 'used up', but it can be transferred from one place to another in such a way that it becomes dissipated and less useful. The rule of conservation of energy prevents energy being used up. In a car engine, energy is wasted through transfers to the environment by sound and heat. Some of this heat is generated in combustion; some is generated in the friction of the various moving engine parts and in the contact with the ground.
4. This is good thinking and reflects current teaching ideas that are being promoted in schools.
5. This is good thinking and reflects current teaching ideas that are being promoted in schools.
6. This kind of thinking is potentially controversial. However, looking at Feynman's definition of energy it would seem this is the case. We like to give things some sort of concrete existence, but in physics many ideas are just that; ideas or models.

Additional resources

- Practical physics http://www.nuffieldfoundation.org/practical-physics provides information on practical activities in physics for 11-19 year olds.
- SEP booklets (downloadable pdfs): Energy storage, Making energy real, Building materials, Solar power, Wind power, all at http://www.nationalstemcentre.org.uk/elibrary/
- IoP: Physics demonstration films http://www.nationalstemcentre.org.uk/elibrary/collection/491/physics-demonstration-films
- MIT Blossoms: Quantifying the energy associated with everyday things and events https://blossoms.mit.edu/videos/lessons/quantifying_energy_associated_everyday_things_and_events

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