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CATEGORIZING PUPILS' EXPLANATORY FRAMEWORKS IN ENERGY AS A MEANS TO THE DEVELOPMENT OF A TEACHING APPROACH

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A number of studies (Gilbert and Pope, 1986; Bliss and Ogborn, 1985; Duit, 1984; Watts, 1983) have aimed at presenting as complete a picture as possible of the range of pupils' ideas about energy. We report here the findings of a pilot and case study in which we identify and categorize students' alternative explanatory frameworks on energy, with the aim of developing a teaching approach which can narrow the gaps between student frameworks and those acceptable to the science community.

THE PILOT STUDY

A series of five energy related tasks, the first four of which were taken from Duit (1984), were administered to 175 students, using the interview-about-instances technique developed by Osborne and Gilbert (1980). In this technique students describe examples or non-examples of the physical concepts and situations presented in a series of pictures. The student sample, taken from secondary schools in northern Israel, comprised: 75 grade 9 students who had had no previous instruction in physics; 29 grade 10 students who had studied a one year programme 'Energy and its transformations' (1978); 18 grade 11 students some of whom had taken physics previously and who were about to start a course in mechanics; and 50 12th graders all of whom had studied physics, including mechanics.

The five tasks required the students:

(1) to write down their first three associations with the word energy;

(2) to define or describe the meaning of the word energy;

(3) to write down three examples of the concept of energy;

(4) to predict the height reached by a ball released on a frictionless roller coaster, and to explain the prediction; and

(5) to select three out of fifteen pictures in which they identified the energy concept, to select one picture in which the energy concept did not appear, and to explain the four selections.

In the following we report on the analyses of responses to tasks 2, 4 and 5 which provide information directly related to the aim of categorizing students' explanatory frameworks. Responses to tasks 1 and 3 are not reported here. Task 1 does not bear directly upon the issues discussed in this paper and task 3 was dropped from the revised questionnaire since it was not found productive.

Definitions of energy (Task 2)

This task called for definitions or descriptions of energy, which were classified according to the following listing of alternative descriptive frameworks (a modification of that by Watts, 1983):

1. Anthropocentric- associating energy with human beings;
2a. Depository- some objects have, and expend energy;
2b. Active deposit energy causing or needed for things to happen;
3. Ingredient- energy as dormant in objects and released by a trigger;
4. Activity- in which energy is an obvious activity;
5. Product- energy as a product of a process or a situation;
6. Functional- energy as a 'kind of fuel';
7. Transfer- energy as "something" transferred in an interaction or process.

We classified almost all student definitions with frameworks 2a, 2b & 7 being used more frequently than the others. Thirty six percent of the students used 2 or 3 alternative frameworks. (see Figure 1).

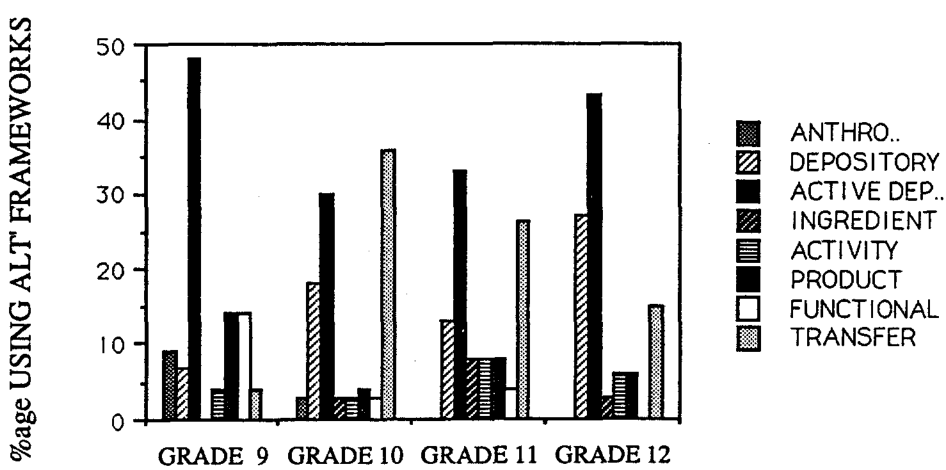

FIGURE 1 DISTRIBUTION OF ALTERNATIVE EXPLANATORY FRAMEWORKS USED BY STUDENTS. BY GRADES, IN PERCENTAGES

Prediction of a mechanical process (Task 4)

This task followed students' explanations about a mechanical process involving conservation. The case chosen was that of a ball released on a roller coaster. Students predicted and explained the position the ball would reach. Responses were expected to reflect differences in the physics programmes followed by the various grade levels. Energy and the principle of conservation are taught in grades 9 and 11. The number of students answering correctly, and using the concept of energy or the principle of conservation, increased after grade 9, decreased from grades 10 to 11, and increased again after grade 11. However, while 66% of the grade 12 students answered correctly, only 56% used the energy concept in their explanations and only 38% used the concept of conservation.

The identification of 'energy situations' (Task 5)

Students selected 3 of the pictures shown in Figure 2, in which they could best identify energy, and explained their selections.

Figure 3 presents the distribution of student choice of pictures. The pictures of the statue and the room were not chosen at all and therefore are not shown. Ninety three percent of students' explanations were found classifiable by the alternative frameworks used in classifying responses to task 2. The most commonly used framework was the active deposit(2b) used by 39%. The anthropocentric framework (1) was used by 21%, transfer (7) by 18%, product (5) by 13%, and depository (2a) by 8% of the students. Each of the other frameworks was used by less than one percent. This task also required students to choose a picture in which the energy concept did not appear. Sixty five percent chose the statue, 30% the room, less than 1% found no such picture, and less than 1%, all in grade 9, chose the girl eating, the sailing boat, or the hot water. Most of the explanations used phrases like "absence of activity", "no movement", "everything is inert". Such explanations are similar to those reported by Bliss and Ogborn (1985) who commented that "the pattern of selection suggests that animacy is a salient feature with which students identify the concept of energy".

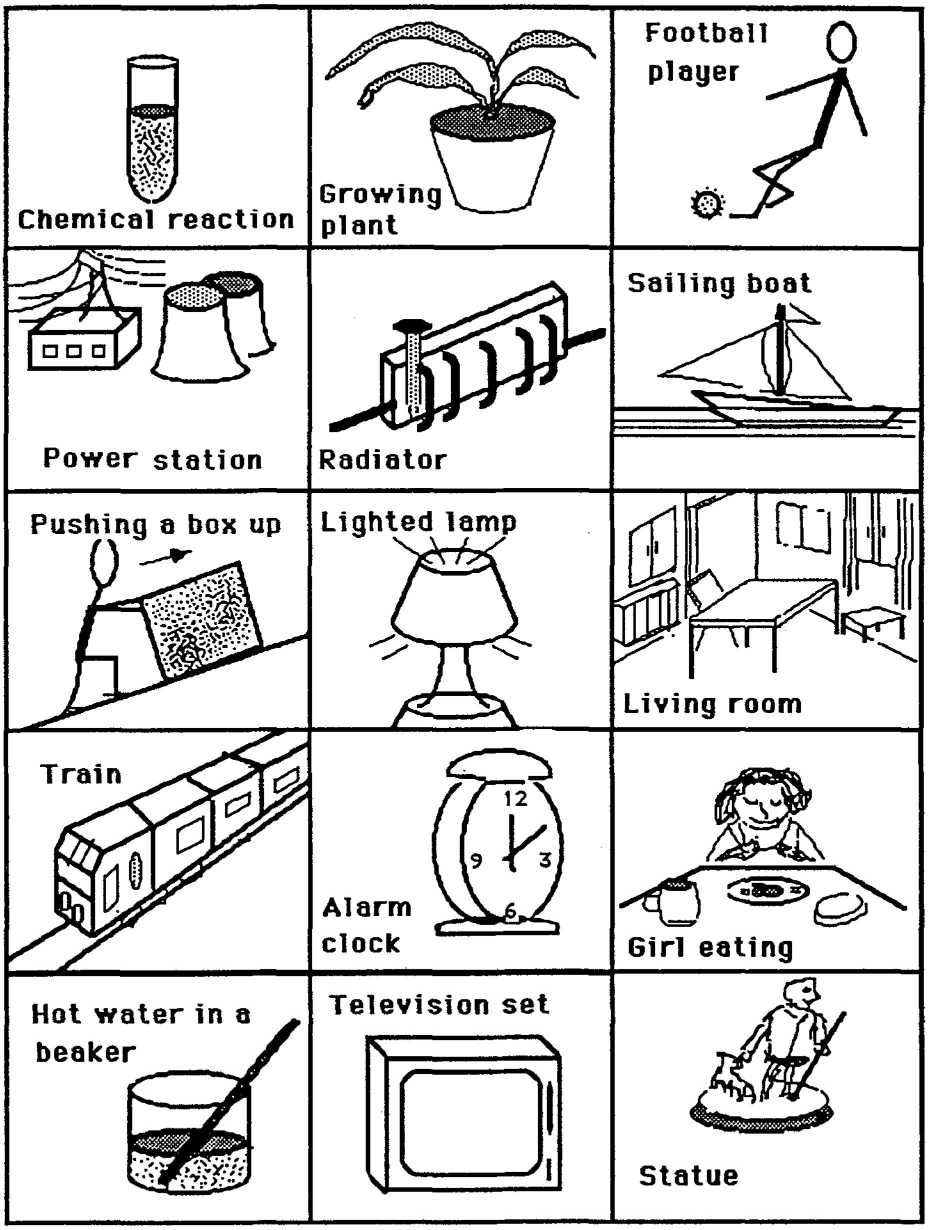

FIGURE 2 FIFTEEN PICTURES

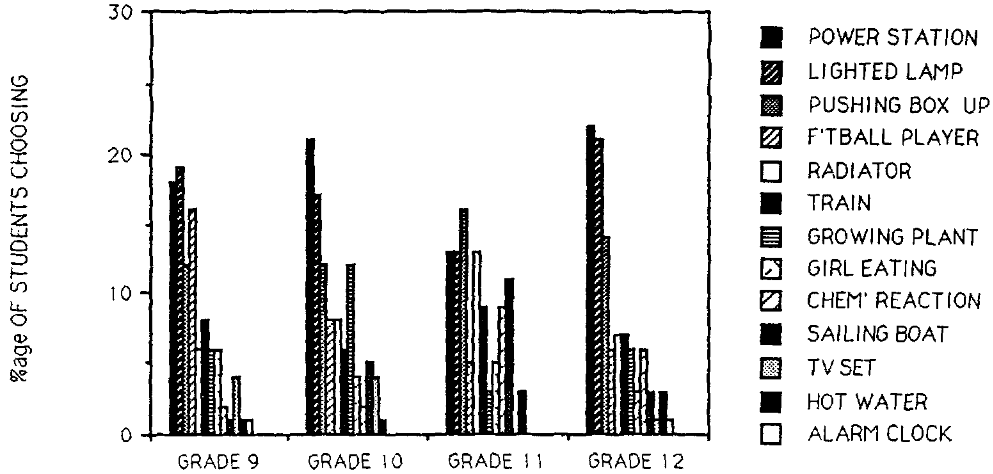

FIGURE 3 DISTRIBUTION OF STUDENTS' CHOICE OF PICTURES IN WHICH ENERGY IS IDENTIFIED. BY GRADES, IN PERCENTAGES

Questionnaire modification

At this stage in the study, the questionnaire was revised. In the first task, students were now asked to write three associations with energy and to write sentences exemplifying the associations. In the second task, students now chose one of five alternative definitions of energy, each of which represented one of the five alternative frameworks most commonly used in the pilot study. The third task and the second part of task 5 were dropped and a second "roller coaster" task, similar to the original task 4, was added.

Questionnaire validity and reliability

Content validity of the revised questionnaire (see appendix) was confirmed by 17 judges from the fields of curriculum development, science education and physics. A total of 122 students, in grades 9-11, answered the revised questionnaire and two judges classified responses. Inter-judge agreement (excluding task 2 which was a multiple choice item) ranged from 78% to 98%. Students were retested on the same questionnaire one month later. No significant difference was found between students' responses on the two occasions for any of the questions.

Pilot study outcomes

At the grade 9 level it appears that student associations with energy are primarily with physical concepts and with phenomena, the former increasing steadily to become very dominant in grade 12, and the latter decreasing steadily. Performance on both tasks 2 and 5 suggests that the active depository (2b) is the principal explanatory framework employed at all year levels except the tenth. The depository (2a), was employed increasingly in grades 11-12, while transfer (7), the closest to a scientific framework, was prominent in grade 10 but used decreasingly in grades 11 and 12. Responses to task 4 and students' explanations of their responses indicate that about half of the grade 12 students did not use the concept of energy in dealing with the problem, and almost two thirds made no use of the concept of conservation.

THE CASE STUDY

The case study was the next step in developing a learning programme to restructure students' alternative explanatory frameworks on energy and bring them closer to accepted notions. Whereas the pilot study analysed written responses to tasks, the case study, carried out with small groups of students, was designed to encourage in-depth discussions of the ways in which students dealt with the tasks. The study proceeded in two stages. The aim of the first stage was to identify explanatory frameworks which could best be used as a basis for conceptual change. In the second stage, students were confronted with statements about situations (pictures) made on the basis of one or other of the frameworks identified in the first stage and were encouraged to identify the characteristics of these statements. It was expected that this would lead, by way of greater understanding of statements about physical situations, to a concept of energy more in keeping with a scientific explanatory framework. The case study population of 35 students comprised 16 grade 9 students with no previous instruction in physics; ten grade 10 students after one year of physics; and nine grade 11 students who had studied physics, including energy, in grade 9, and optics and waves in grade 10.

Case study - stage 1

Students first responded to the revised questionnaire on energy and were then interviewed in groups of 4 or 5 students from the same grade level. Meetings began with a discussion of questionnaire responses and continued as "interviews-about-instances" (Osborne & Gilbert, 1980). "Instances" chosen were presented in fifteen pictures (Figure 2). Interviews opened with a question like "Is there energy here?". Analysis of explanatory frameworks was based mainly on transcripts of students' descriptions ofthe pictures. One outcome of this analysis was that framework "7" was modified to become:

7a. <u>Flow transfer</u> - in which energy is seen as a kind of fluid transferred in some processes;

7b. <u>An accepted scientific concept</u> - "When two systems interact, i.e. when a process takes place, something which we call energy is transferred from one system to another". (Energy and its transformations - 1978).

It was found possible to classify 96% of students' descriptions according to the modified list of frameworks and to draw a number of conclusions about the use of alternative frameworks:

1. Frameworks "1", "2a" and "2b" are used frequently, but with decreasing frequency after the study of physics.
2. Frameworks "3", "6" and "7a" are used very rarely.
3. Frameworks "4" and "5" are used increasingly after studying physics.
4. Framework "7b", acceptable in the science community, is rarely used either before or after studying physics.

Responses to the associations task were classified according to Duit's categories (1981). Word associations were found to dominate in grade 9, but became less important with time, while as in the pilot study, energy associations with physical concepts were found to increase and to become dominant in grade 11.

Tasks 4 and 5 deal with processes involving the principle of energy conservation. As expected, student success on these tasks, and in using the concepts of energy and energy conservation, increased considerably with physics instruction. However, more than half the students used non-science ideas to explain their answers. Sixty percent of the 10th-11th graders did not use the term energy, and 80% did not use the principle of conservation.

<u>Conclusions from stage 1 of the case study</u>

Student responses to the tasks on association and on conservation show some success in learning, but very few students see energy within a scientifically acceptable framework such as "7b". We assume that teachers have a very limited degree of success in teaching about energy in transfer processes which take place when systems interact. In fact, students continue to hold the same alternative frameworks held before studying physics. We believe that this lack of success in teaching towards a scientifically acceptable concept of energy results in part from teaching which takes little or no account of students' alternative frameworks.

Three alternative frameworks "1", "2b" and "5", are of particular interest as they are held by many of the students in the study. The anthropocentric framework, "1", in which energy is associated with human beings, is unacceptable and very limited. It is exemplified in the following transcript of a pupil's comments on the picture of a man pushing a box up a hill (Fig. 2).

> "It's like a football player. He moves his body. He's doing an activity so there is some energy... He moves himself and he moves the box... He climbs up and uses his energy".

The student focusses attention on the man, in contrast with the same student's description of a similar situation in which the man is replaced by an electric motor.

> "There is a kinetic energy as a result of the motor pulling up the box... and also potential energy when the box is up".

Framework "2b", in which energy is seen as causing, or needed for, things to happen, and framework "5", in which energy is seen as a product of some process, are also limited frameworks representing limited views of the real world. However, each of them can be seen as a component of "7b" which is superior to both in that it maps onto larger sections of the real world and relates to a larger range of phenomena. Thus frameworks "2b" and "5", both of which are used by a majority of the case study group, are both valid albeit limited ways of thinking about energy. Assuming that they can be used as building blocks in teaching toward an acceptable view of energy, we proceeded as follows.

<u>Case study - stage 2</u>

Students' statements made about situations (pictures) presented in earlier discussions were recorded and for each picture, printouts were prepared of all statements categorized as representative of frameworks "2b" and "5". Small discussion groups were then presented first with the pictures and the relevant "2b" statements, and then with the same pictures and relevant framework "5" statements. In each case students were asked to examine the statements carefully and to characterize the ways in which the concept of energy had been used. Our intention in confronting students with these statements was to make provision for the identification and juxtaposition of the views of energy expressed in the "2b" and "5" statements. We present here a very limited excerpt of statements and comments.

Statements categorized as "2b"

1) Electricity in a power station needs energy to make it work.

2) The lamp runs on electricity...on electrical energy.

3) To heat the water you need some energy.

Students' comments on the "2b" statements

1) Energy makes things move...it changes from one kind to another.

2) I didn't look for it but I found only one side here...they keep repeating things like "needs energy" and "energy causes"... there's another side that's missing.

3) Energy activates things.

Statements categorized as "5"

1) Work in a power station creates electrical energy.

2) Kerosene uses oxygen as it burns and that creates energy.. that's the light and the heat.

3) When you shout you create sound energy.

Students' comments on the "5" statements

1) Everything that works here creates energy, instead of the energy making things work.

2) There isn't just energy in the air, it's made from something.

3) I think that here all sorts of actions cause energy. There it was the opposite, energy made activities.

We now wished to focus upon both the "2b" and "5" frameworks in order to move toward a more generalizable view of energy. The students were therefore asked to review their comments upon the pictures while bearing the foregoing discussions in mind. They seemed to find no difficulty in combining both aspects of energy. In one of the groups, for example, discussion about comments made on the picture of the radiator led to statements like:

1. The heating element gets energy from the electric point that comes from the power station...the electrical energy helps the element to create the heat energy.

2. I think the power station creates electricity, the electrical energy is passed on to the heater and then heat energy is created when the heating element works.

3. There's a chain of actions. If a waterfall provides energy...a special thing creates electrical energy and the electrical energy is changed to heat energy by the heating element.

In the discussions that followed, similar generalizing views on energy were expressed with respect to all of the pictured situations. We have noted that in going through this process, students were first asked to identify characteristics common to "2b" statements, then to identify characteristics common to "5" statements, and finally to discuss the pictured situations in light of these characteristics. We found that of the 35 case study students, 3 were unable to identify the common characteristics of either group of statements and 4 were able to identify these characteristics only after orientation to specific instances. For example, the following dialogue shows how the teacher helps a student who has difficulty in identifying a characteristic of "2b" statements:

Student: I think something is supplying, that causes energy...

Teacher: I don't understand.

Student: For all energies there is something that activates them, that gives the strength.

Teacher: Give me an example.

Student: In "the lighted lamp", I wrote "activated by electrical energy from a source like the electric company".

Teacher: And that means?

Student: Ah! Energy activates the lamp! That's the characteristic.

Twenty eight students found no difficulty in identifying the characteristics of the two groups of statements, and 17 were able both to identify the characteristics of each group and to describe relationships between the two groups of statements. This is exemplified by the following student statements:

1) The common thing here is talk about creating energy...but energy isn't made, it's just in another form. In a power station that's worked by a waterfall that the water changes into electricity, the electricity is made by the force of the water, but the force is just another kind of energy.

2) I want to connect it with the things we did before. First of all the energy makes things work. We agreed on that, right? Then, when it makes something work, energy is made... it doesn't matter what kind. Then as soon as energy makes something work... some kind of energy is created.

3) The idea is that energy is the result of something. It doesn't just cause something, it's made by some activity or other.

In our view, understanding of the relationships between the two groups of statements is the logical step which makes it possible to combine frameworks '2b' and '5' to form framework '7b'. This suggests that the development of student facility in identifying approaches to the energy concept, and confrontation with alternative approaches, does provide a way of narrowing the gap between students' alternative conceptual frameworks and a framework acceptable to the scientific community.

Classroom teaching about energy does not normally make provision for the scrutiny of alternative explanatory frameworks. Nor does it normally take into account the explanatory frameworks held by students prior to the study of energy related topics. It usually proceeds by means of a variety of approaches in which students are provided with experiences related to instances of energy in various forms, transformation from one form to another, energy calculations, solving of energy related problems, and laboratory experiments confirming the principle of conservation. This is borne out by a scrutiny of syllabi, guidelines and practices in school science such as that carried out in almost thirty countries around the world within the framework of the Second International Science Study (SISS) (Finegold and Raphael, 1988). Some of the curricular case studies carried out as part of the SISS (Finegold and MacKeracher, 1985), point to a need for change in the concept of energy as taught in schools. The findings reported here suggest that the teaching method explored, used with small groups or adapted to the needs of the standard classroom, can enrich schooling by making provision for learning about energy in a scientifically acceptable manner.

ACKNOWLEDGEMENT

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APPENDIX

QUESTIONNAIRE ON ENERGY (Abridged)

1. What are the first three words you think of when you hear the word "energy"? Write three sentences, each including one of these words and the word "energy".

2. Here are five sentences about energy. Mark the one closest to your own definition or description of energy.

   A. Energy is a property deposited in some objects, e.g., "There is electric energy in a battery".

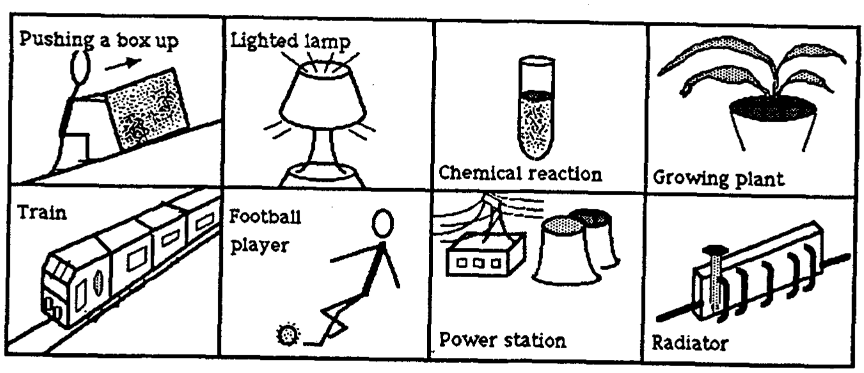
   B. Energy causes some objects to carry out some activities, e.g., "Solar energy heats the water in the boiler".

   C. Energy is something transferred from one object to another and appears in different forms, e.g."A TV set transforms electrical energy into light and sound energy".

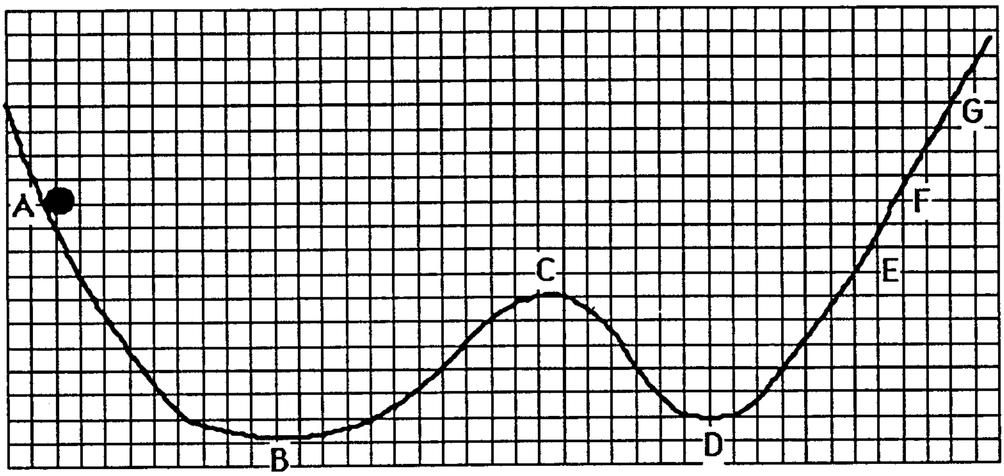
   D. Energy is an activity, e.g., "A fire burning, a phone ringing, people running".

   E. Energy is created by some activities, e.g., "A turning wheel drives a turbine that creates electrical energy".

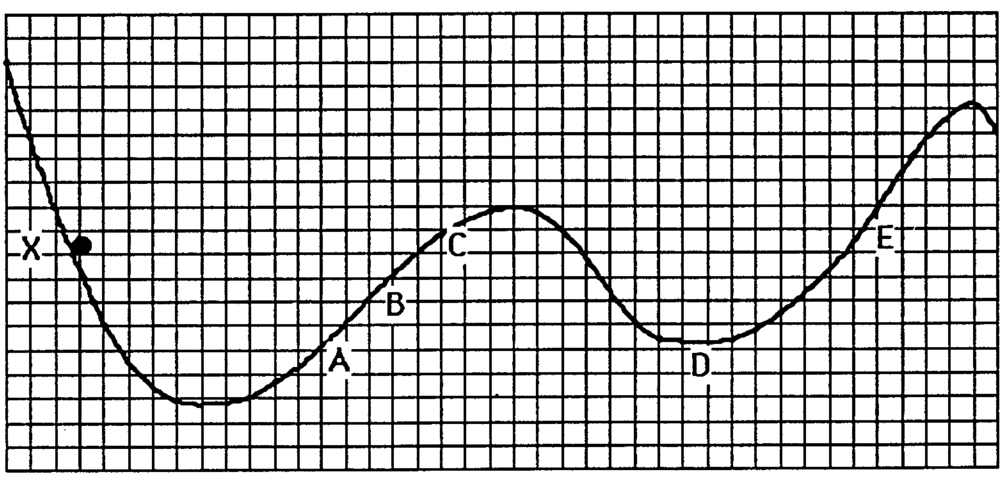
3. Examine these pictures and choose three involving energy which you understand best. Explain each choice in 1 or 2 sentences using the word 'energy'.



4. A ball is released at "A" on the path shown and rolls freely. Mark the spot the ball will reach before it begins to roll back. Explain your answer.



5. A ball is released at "X" on the path shown. Mark the furthest spot you think the ball will reach on the path and explain your answer.



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