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Learning the energy concept in school—empirical results from The Philippines and West Germany

Reinders Duit

Energy education has become an area of major interest for those who are, or feel, responsible for school learning. Teachers, politicians and the public agree that school teaching should equip students with the knowledge, skills and abilities needed to live in a world faced with rising energy demands and shrinking energy resources. They also agree that contributions from many school disciplines are needed for a comprehensive insight into problems of sufficient energy supply.

Physics instruction is expected to introduce the physical energy concept and there are several problems connected with this expectation. On the one hand, the fact that the energy concept used in discussions about energy supply is not necessarily the energy concept used in physics is often overlooked. This is why a deliberate analysis is needed to understand which aspects of the physical energy concept really facilitate understanding of the 'energy problems' facing society. On the other hand whether these aspects can be grasped by students during physics lessons must also be investigated.

Research interests at the Science Education Centre at The University of the Philippines (UP-SEC) and the Institute for Science Education at the University of Kiel (IPN) converged on these problems. An empiricial study using the same questionnaire in Manila and Kiel was used to investigate learning of the energy concept during grades 7–10 in school physics teaching (Duit and Talisayon 1981). This article presents some findings of the study.

The energy concept

Consideration of the different paths leading to the physical energy concept resulted in five basic aspects of the energy concept. These aspects may serve as a framework for research in the area of teaching energy in school.

(1) *Conception of energy*. This is an overall aspect. It refers to the philosophical framework underlying the energy concept. Some common conceptions are: energy is a precondition (or even ability) for doing work or doing a useful job; energy is 'something' which is able to bring about changes in the world; energy is a special (very general) kind of fuel. Sometimes energy is seen as a quasi-material 'something' (see e.g. Schmid 1982). Such a conception, i.e. thinking of energy in terms of a thing, is not in line with the usual conception of energy in physics (see e.g. Warren 1983). In physics, energy is a very abstract quantity balancing processes in nature and technology.

(2) *Energy transfer*. The quantity we call energy, as conceptualised in accordance with aspect (1), can be transferred from one system to another (from one place to another).

(3) *Energy conversion*. The quantity we call energy can occur in several forms. Energy can be converted from one form to another.

(4) *Energy conservation*. When energy is transferred from one system to another, or when energy is converted from one form to another, the amount of energy does not change.

(5) *Energy degradation*. When talking about energy one cannot avoid talking about entropy too. A very simple notion of entropy is needed for the purpose of introducing energy to the lower grades (e.g. grades 7–10). When energy is converted during a process the amount of energy is conserved.

Reinders Duit *is a member of the Physics Department of the Institute for Science Education (IPN) at the University of Kiel, West Germany. For several years he has been involved in the development of a physics curriculum. His main research interests are in the field of conceptual development with particular reference to students' everyday notions. He has written several books and articles and is co-editor of* Naturwissenschaften im Unterricht, *a German journal for physics and chemistry education.*

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Although the amount of energy has not changed, the 'value' of the energy has decreased. The different forms in which energy occurs have different values. The energy of a moving body (kinetic energy) and the energy transported while current is flowing (electrical energy), for instance, are of high value. It is possible to convert them—in principle—totally into any other energy form. The energy which is transported due to thermal exchange (heat energy) is of lower value (especially at low temperature) because it can be converted to ordered kinetic energy only to a certain extent.

Understanding energy supply problems

A few remarks can be made here to show the significance of the basic aspects of providing students with an understanding of energy problems in society.

The conception of energy (aspect 1) underlying introductory physics courses is of crucial importance here. If, for instance, energy is introduced as the ability to do work and is more or less restricted to mechanics, the benefit of such a conception in facilitating understanding of energy problems is rather limited. A much more comprehensive conception of energy including other areas (e.g. heat, light, electricity) is needed.

There also seems to be another problem. If physics instruction is oriented more or less exclusively towards the physical conception of energy (which is a very abstract quantity) the benefit in terms of understanding problems of energy supply is low. This is because the meaning of the word energy in colloquial language and also in discussions of energy problems is rather different from the abstract notion which physics attaches to energy. Therefore, in teaching physics a compromise between adequate physics and the demands of understanding energy supply problems has to be found. It is obvious that for the purposes discussed here some knowledge of energy transfer and energy conversion is needed.

The question as to whether understanding the energy conservation aspect can contribute to an insight into energy supply problems is not so easy to answer. Of course, energy conservation is a basic principle in physics and an energy concept without this aspect would not be the physics concept of energy. But this answer is not sufficient from the viewpoint discussed here. This aspect is important here too. Many problems about energy supply concern the fact that energy is being used to run a certain process. What happens to the energy when the process is finished (e.g. heating up the air) is very seldom considered. The idea contained in the principle of energy conservation—that energy is not lost—may strengthen the insight that one cannot get rid of energy (mostly heat) easily, and that one has to follow the flows of energy carefully in order to avoid damaging the environment.

It is easy to explain why students should know something about the value of different energy forms (the energy degradation aspect). First, the notion of energy conservation may hamper an understanding of sufficient energy supply: the students may wonder why there is an energy supply problem when energy is not lost (is conserved). Also researchers in the field of energy supply know that the most important task is not only to save energy but to minimise energy degradation.

The empirical study on learning energy

The following samples took part in the study:

Manila, The Philippines

- 87 students, grade 6, elementary school *before* physics instruction
- 89 students, grade 10, high school *after* physics instruction in grade 7 and in grade 10

Kiel, West Germany, high schools

- 147 students, grade 6, *before* physics instruction
- 67 students, grade 8, *after* physics instruction in grades 7 and 8
- 171 students, grade 10, *after* physics instruction in grades 7–10

Basel, Switzerland, high schools

- 76 students, grade 7, *without any* physics instruction
- 124 students, grade 10, *without any* physics instruction

Students in grade 6 are about 11–12 years old, students in grade 10 about 15–16 years. In the Philippines elementary school attendance (grades 1–6, all ability levels) is compulsory. The high school which follows is not compulsory; it leads to college level. Students in Switzerland and Germany attended high schools (*Gymnasien*), i.e. schools of the upper ability level. The samples in Switzerland (Basel) served as 'control samples' because these students—in both grades 7 and 10—had no physics instruction at all.

Energy is taught in Manila and Kiel in a more or less 'traditional' manner via the concept of work. In Manila (Philippines) the students get a first introduction to this concept in grade 7. In grades 8 and 9 there is no physics instruction. In grade 10 physics is taught for five periods (45 min each) a week. Energy is introduced as the ability to do work. Only a slight emphasis is placed on the principle of conservation of energy and almost no emphasis on energy degradation.

In Kiel (West Germany) the students are taught physics during grades 7–10 (two periods a week, 45 min each). Energy is one of the main topics of physics instruction; the concept is introduced in

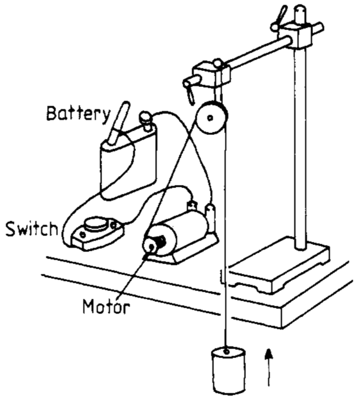

Figure 1 An electric motor connected to a battery lifts a weight when the switch is closed (task 4)

grade 7 and enlarged during grades 8–10. Energy is defined as a precondition for doing work. Although this introduction is oriented towards mechanics, it is not restricted to this area; energy forms such as electrical energy, chemical energy and heat energy are also considered. The principle of energy conservation is given considerable attention. In particular, idealised (frictionless) processes of mechanics are employed to convince the students that this principle is true. Energy degradation is paid almost no attention.

The questionnaire

The first part of the questionnaire focuses on the meaning of the words (the names of the concepts) energy, work, force and power. In this part the students are asked to state the meanings the concepts have in physics if they have already had physics instruction and, if not, to state the colloquial meaning.

Task 1. Students are asked to write down their *associations* with words presented for 30 s on the blackboard. Every 30 s a new word follows.

Task 2. Students are asked to *define* or *describe* the meaning of energy, work, power and force.

Task 3. Examples are given for energy, work, power and force.

Task 4. Students describe the process shown in figure 1—an electrical motor connected to a battery lifts a weight when the switch is closed.

Some brief comments on the tasks of part 1 follow. A more detailed analysis is given by Duit (1983). The four tasks throw light upon different aspects of meaning.

Associations provide information about the ideas which come spontaneously to the minds of students when they are confronted with words we use in physics as names for concepts. Of course, the information gained is limited. If a student writes down a word (associates), we do not know why he or she is doing this, i.e. we do not know anything about links to the stimulus word. Furthermore, we do not know anything about the meaning the student relates to the word at the moment of association. If a student writes down 'force' we do not know whether the physics or the everyday meaning is intended. Nevertheless, associations provide researchers and teachers with a rough insight of meanings attached to physical terms by a group of students. Important information about the prior knowledge of students is gained.

Definitions lead a little nearer to the 'logical thinking' of the students in connection with a concept. But it must be borne in mind that one cannot distinguish whether a definition is based on 'understanding' or has merely been learned by heart.

The ability to give *examples* is currently seen as an important indicator for concept learning. The examples are meant to support the information gained through associations and definitions. Whereas the latter throw light upon more general and abstract aspects, examples are oriented to a greater extent to situations, processes and activities.

The *application* of the words to describe a process give some indication as to whether the students are able to make use of the concepts. Of course, the results of tasks 1–4 do not provide a comprehensive insight into learning the concepts energy, work, power and force. They deal only with one area—the meaning of the words—and, of course, they do this only in part. For a more comprehensive insight, further tasks had to be included in the questionnaire. Because of time limits (set mainly by the limited patience of the students) only applications of the principle of conservation of energy are contained in the second part of the questionnaire.

In the second part the first two tasks are concerned with the motion of a ball rolling without friction and unpowered along curved paths (task 5, see figure 2) and over different-shaped slopes (task 6, see figure 3). In task 5 the ball is released at points A, B and C. In task 6 the ball is passing point A with a speed sufficiently great for it to go over the slopes. In task 5 the same height is reached; in task 6 the speed at point B is as great as the speed at point A. The students are asked to predict the height or the speed of the ball and to explain the prediction. The purpose is to find out whether the students are able to apply the energy concept, and especially the principle of conservation of energy, or whether they make use of notions stemming from everyday experience. (The idea for tasks 5 and 6 stems from Dahncke 1973.)

Many students in Manila and Kiel mention work

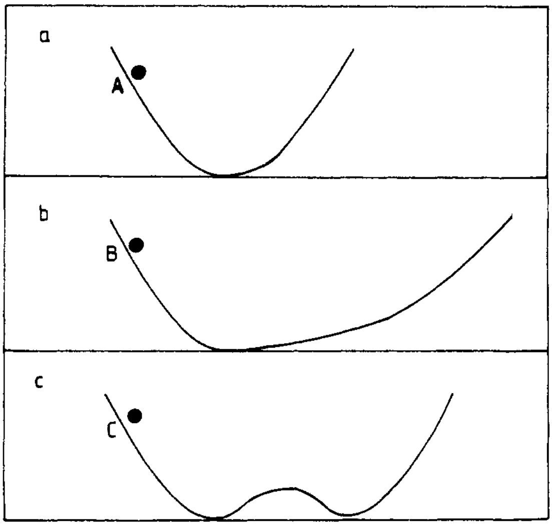

Figure 2 Frictionless ball rolling along curved paths (task 5), released at points A, B and C

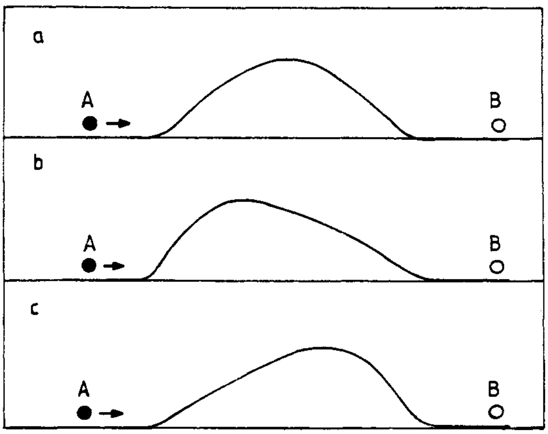

Figure 3 Frictionless ball rolling over slopes. The ball reaches point B with the same speed with which it was released at A (task 6)

when describing energy. Students in the Philippines prefer the definition 'energy is the ability (or capability) to do work'. Students in Germany use other definitions too, namely 'energy is necessary for work' and 'energy is stored work'. Both samples, therefore, provide definitions used in their textbooks. A critical analysis of the definitions reveals that a majority of the students in both Manila and Kiel mention only superficial aspects of the energy concept. The definitions 'energy is the ability to do work' or 'energy is stored work' often seem to be no more than a notion retrieved from memory and not based on understanding. The definitions which do not use work indicate some uncertainty. Where force and power are concerned, there seems to be no difference in meaning between these terms and energy. A confusion between energy, work, power and force is apparent in many students after physics teaching. As far as the basic aspects of the energy concept are concerned, the aspects energy transfer, energy conversion and energy conservation are only mentioned by a small number of West German students. Energy degradation is not mentioned at all.

Associations with energy (task 1)

The pie chart in figure 4a indicates that for German students in grade 6 energy is very closely linked to current (electricity) and fuels. Students in grades 6 and 10 differ in one remarkable aspect only (compare figures 4a, b)—the percentage of 'physical terms' has increased. This increase is caused mainly by a larger number of energy forms and words linked with energy, such as energy conversion. The general features of the charts are more or less the same for grades 6 and 10. For instance, current and fuels are still among the associations with the highest percentages in grade 10.

It is interesting to note that the associations from the Philippines are different both in grades 6 and 10 from those in Germany (see figures 5a and 5b). Whereas the charts for German students reflect a close link of energy with fuels and current (electricity), this is not true for the students in the Philippines. For them, energy seems very much to be linked with strength (compare the percentage of students mentioning strength when defining energy; see table 1).

In the Philippines and in Germany a remarkably large number of students associate energy forms in grade 10. Although only some students mention energy conversion when defining energy (table 1), many of them seem to be aware that energy can occur in several forms.

Examples and applications (tasks 3 and 4)

The most important findings concerning tasks 3 and 4 of the questionnaire can be summarised as follows.

The examples given for energy support the findings gained from studying the associations. For German students in both grades 6 and 10 energy is closely linked to fuels and electricity. Furthermore, nearly 40% of the examples given are 'things' (e.g. fuels, sun, power plant, battery, lamp). For students in the Philippines energy seems to be much more process-oriented. More than 66% of the examples contain a process (about 20% physical activities, about 30% processes connected with electricity).

Energy seems, therefore, to have different meanings in colloquial language in the Philippines and in Germany. Whether these differences are due to the different languages (English, German)

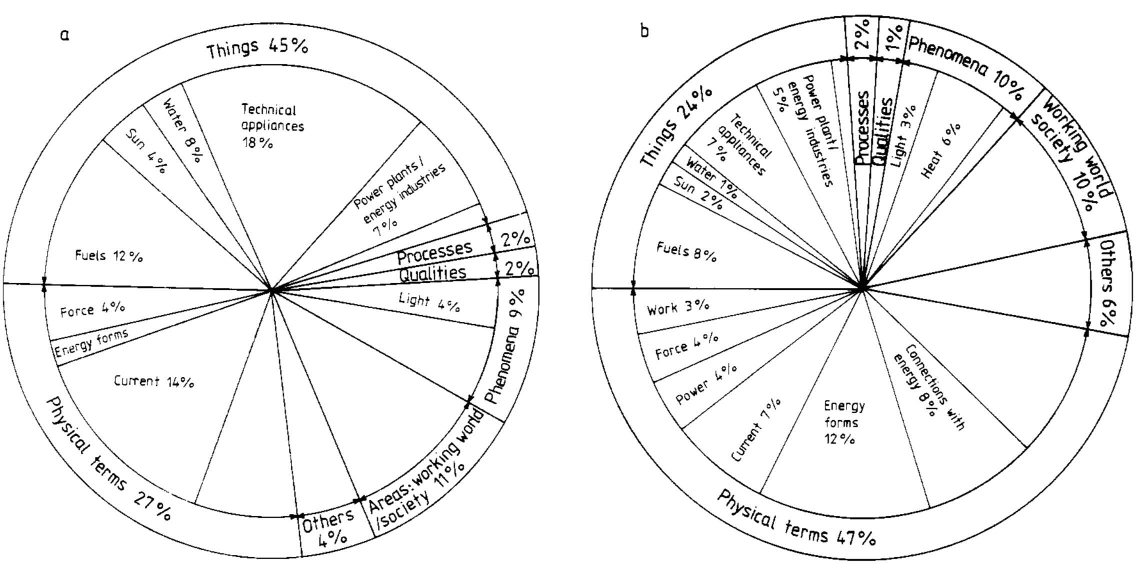

Figure 4 Associations with energy for students in Kiel, West Germany. **a,** 147 students, grade 6, *before* physics instruction. **b,** 171 students, grade 10, *after* physics instruction in grades 7–10

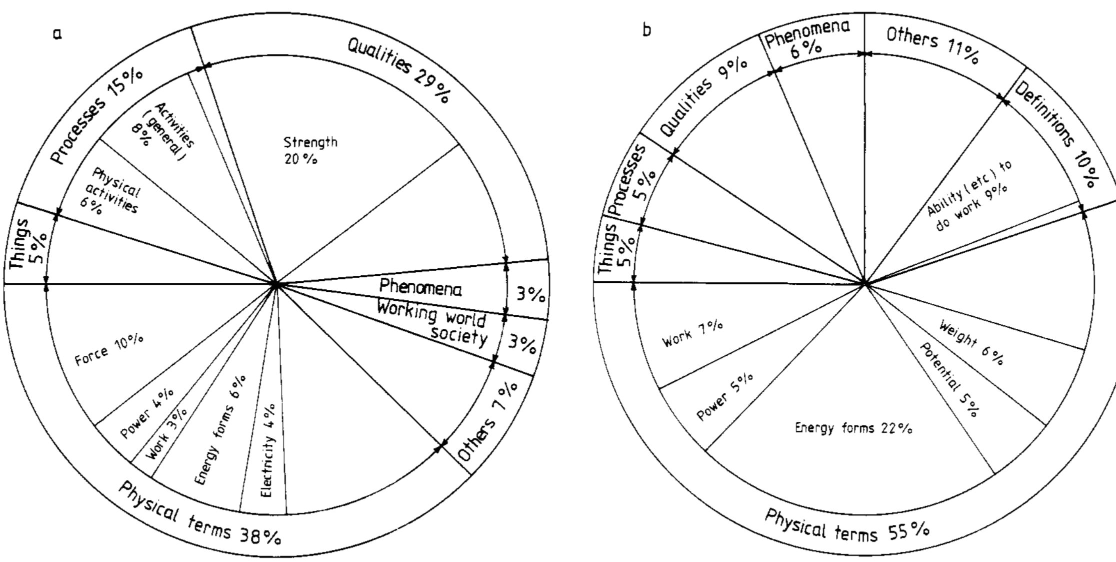

Figure 5 Associations with energy for students in Manila, the Philippines, **a,** 87 students, grade 6, *before* physics instruction. **b,** 89 students, grade 10, *after* physics instruction in grades 7 and 10

or to the different cultural contexts cannot yet be determined.

The general features of the association charts for grades 6 and 10 are the same. This is also true for the charts concerning examples. The differences between students before and after some years of physics instruction are even smaller. The meaning of energy in colloquial language and in physics, as reflected by associations and the examples given for energy by the students in our study, seem therefore to be very similar. We will come back to this aspect later.

The use of energy when describing the simple process of task 4 reveals considerable uncertainty on the part of the students. It underlines the corresponding conclusions from task 2 (definitions).

Explaining mechanical processes

The questionnaire contains tasks (e.g. tasks 5 and 6) which deal with the application of conservation of energy. Students were asked for a prediction and an explanation of their prediction. Some results are shown in table 2. Students in the Philippines have great difficulties with these tasks. A small number are, for instance, able to predict in task 5 the correct height on the right-hand side when the ball is released, but almost no one is able to predict the height on the left-side when the ball goes back. For the German students there is a remarkable difference between grades 6 and 10 in tasks 5 and 6. The students in Switzerland, who have had no physics instruction at all, gain only a small increase between grades 7 and 10. Therefore, the increase of correct predictions in Germany may be ascribed to the impact of physics teaching.

Although the impact of physics instruction is visible for the German students in tasks 5 and 6, it is discouraging that only a small number of students make use of the word energy and the principle of conservation of energy when explaining their predictions. Although the questionnaire was presented in a physics lesson and deals with associations, with definitions of and examples for energy (and work, power, force as well), most students do not make use of these terms but prefer words and notions stemming from their everyday experiences. Sometimes a mixing up of physics knowledge and 'everyday' knowledge is apparent. One student, for example, predicted 'the same height' in task 5a and explained this within the framework of energy conservation. But in task 5b he gave an incorrect prediction and fell back on explanations stemming from everyday experience.

Summary and recommendations

The findings presented above indicate that physics instruction has not been very successful with regard to the learning of the energy concept. Although significant impacts are apparent, they refer mostly to 'superficial effects'. The general features of the meaning of the word energy in colloquial language and in physics as learned by the grade 10 students who took part in the study are very similar. The main influence of physics teaching regarding the meaning of energy is a closer link with the term work and other physical terms. Furthermore, a larger number of energy forms come to the students' minds when confronted with the word energy. Where applications of the energy concept are concerned, severe limitations of the impact of physics instruction must be reported. Even when describing a simple process using the word energy there is much uncertainty reflected in the students' answers.

When asked for explanations of processes in mechanics, similar problems are revealed. Most students do not use the word energy (or another physics term) to explain a process—they prefer words which stem from colloquial language. They do not employ physics notions like energy conservation either, but prefer notions which stem from everyday experiences.

This summary about learning the energy concept is valid not only for this concept but for the other concepts of the study as well, i.e. for power, force and work. Physics teaching has a significant impact on the 'associative framework' of these concepts. The associations given, for instance, by grade 10 students are mainly 'physics oriented', but the definitions and applications provided by the students indicate that they are only able to make limited use of this associative framework. The general findings of the study presented here are in agreement with findings from many other studies (for overviewers see Driver and Easley 1978, Archenhold *et al* 1980, Jung *et al* 1982, Sutton

Table 1 Definitions of energy (task 2). Figures given are percentages

	Philippine high schools grade 10 (N = 89)	*German high schools Grade 8 (N = 67)*	*Grade 10 (N = 171)*
Mentioned terms			
Work	60	36	42
energy necessary for work	5	18	21
ability to do work	55	9	9
energy is stored work	—	7	7
Force	6	10	14
Power	11	4	7
Current, electricity	1	15	12
Strength	9	—	11
Energy conversion and transfer			
Energy forms mentioned	3	7	12
Energy conversion	1	10	10
Energy transfer	—	4	1
Energy conservation	—	3	11

and West 1982).

Physics instruction, for reasons which cannot be discussed here, has severe difficulties with respect to instilling the physics meanings of concepts in students' minds and in convincing students that, in some situations, physics notions are more appropriate as explanations than notions stemming from everyday experience.

Where the basic aspects of the energy concept are concerned the study detects limitations, especially with respect to conservation of energy. This aspect seems to be familiar only to a small minority of the grade 10 students in Kiel. Most students do not mention this aspect when explaining simple idealised processes of (frictionless) mechanics, although similar processes had been employed in physics instruction in order to convince them that the principle of energy conservation is valid. Other studies also report learning difficulties concerning energy conservation (e.g. Solomon 1982, Watts 1983). Energy degradation is not mentioned at all by the students—it has not been discussed in the course of physics instruction.

A final remark concerns the question behind the study reported here: can physics teaching contribute to an understanding of the energy problems confronting society? If the analysis of the role of the basic aspects needed for such an understanding is correct, the contribution physics instruction makes to the classes involved in the study is small. If the role of physics instruction in the area of energy education is to be promoted, another conception of dealing with energy in the course of physics teaching is necessary. Energy should not be closely linked to work, but to a more comprehensive notion right from the start.

Physics instruction should not waste time in trying to convince the students that the principle of conservation of energy is valid by using idealised mechanics processes. It seems to make more sense to spend this time in introducing the topic of energy degradation. There are already proposals for dealing with this aspect (see e.g. Schlichting 1979, Ogborn 1981, Solomon 1982, Duit and Häussler 1983) in the lower grades. Of course, the aspect of conservation of energy should not be banished: all basic aspects of the energy concept are needed for an insight into both the physical energy concept and problems of energy supply. It may be interesting to note that dealing with energy degradation aids understanding of energy conservation. This seems to be true for the following reason. The principle of conservation of energy contradicts, to some extent, everyday experience. Energy always seems to disappear. Energy is always dissipated. The notion of energy degradation explains this 'disappearance'. Energy is not lost but is of lower value.

Acknowledgments

The study described in this article was carried out during the author's stay at the Science Education

Table 2 Results for tasks 5 and 6; task 5a is the slope shown in figure 2**a**, task 6a that shown in figure 3**a**, etc. Figures given are percentages

		Manila		*Kiel*			*Basel*	
		grade 6	*grade 10*	*grade 6*	*grade 8*	*grade 10*	*grade 7*	*grade 10*
Task 5								
Prediction of correct height	5a	—	—	7	28	47	25	32
	5b	—	—	3	10	26	12	15
	5c	4	3	7	18	33	11	17
Use of energy for explanation	5a	1	16	1	12	35	3	6
	5b	2	13	1	6	26	1	6
	5c	—	7	1	3	22	—	4
Use of energy conservation for explanation	5a	—	—	—	9	26	—	3
	5b	—	—	—	4	18	—	2
	5c	—	—	—	1	15	—	2
Task 6								
Prediction of correct speed	6a	61	42	41	67	75	45	56
	6b	13	4	20	18	35	13	28
	6c	8	7	13	16	31	14	23
Use of energy for explanation	6a	—	4	1	1	22	1	7
	6b	—	2	1	—	18	1	6
	6c	—	—	1	—	17	3	6
Use of energy conservation for explanation	6a	—	—	1	—	16	1	3
	6b	—	—	—	—	9	1	2
	6c	—	—	—	—	9	—	2

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A short history of the International Physics Competition

R Kunfalvi

Competitions provide incentives for the talented and have long standing traditions in several countries, especially in England, France and the USA. In countries where there are more young people who want to study at university than there are places available, competitive entrance examinations serve to select the brightest. Competitions are also a useful means of searching for and discovering talents, and encourage and stimulate young people to achieve better results.

Competitions in mathematics have a longer tradition than those in other subjects. In Hungary the Mathematical and Physical Society started to organise mathematical competitions in 1894 on the initiative of the physicist Roland Eötvös. Similar competitions in physics followed in 1916. The official school authorities have organised yearly competitions since 1923 in different subjects including science, the humanities, economics and many practical subjects. These are very popular since prizewinners are given preference when entering university. In the USSR the first competition in physics was held in 1939, in Poland in 1951 and in Czechoslovakia in 1959. Many other countries have since started national competitions, first in mathematics and later in physics.

The first International Mathematical Competition was held in 1959. International Competitions are called often 'Olympiads' although the use of this expression is not correct as the original Greek word means the four-year interval between Olympic games. The Rumanian Mathematical Society invited seven countries to participate in the first contest. The 24th International Mathematical Competition in 1983 in Paris attracted 32 teams from five continents.

International Physics Competitions began later and developed much more slowly. Physics seems to be somewhat less popular with the various authorities. After long talks between Czechoslova-

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