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ABSTRACT

Two studies on students' conceptions/notions about the energy concept are presented. The first (study A) dealt with learning the energy concept during a grades 7/8 instructional unit ("energy, work, force, and power"). The second (study B), using students in West Germany, Switzerland, and the Philippines as subjects, examined outcomes of physics instruction in grades 6 and 10 with regard to the energy concept. A two-part questionnaire (included in an appendix along with questionnaire evaluation categories) was used before and after instruction in both studies. The first part focused on the meaning of the words (concept names) energy, work, power, and force. The second part focused on application of the principle of energy conservation in simple mechanics' processes. In addition, some students were interviewed to clarify their responses (before and after instruction). Among the detailed results reported are findings that physics instruction does not alter drastically students' notions about energy. In addition, most students preferred conceptions and notions stemming from everyday experiences. This suggests that energy should not be restricted to the ability to do work, that the traditional way to energy concept via work causes severe learning difficulties, and that energy conservation/degradation should be given more instructional emphasis. (JN)

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STUDENTS' NOTIONS ABOUT THE ENERGY CONCEPT - BEFORE AND AFTER PHYSICS INSTRUCTION

Paper to be presented at the conference on "Problems concerning students' representation of physics and chemistry knowledge"
Ludwigsburg, W-Germany, September 14 to 16, 1981

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1. INTRODUCTION

This paper deals with empirical studies on conceptions and notions of students about the energy concept. Starting point of these studies was my interest as a curriculum developer. In cooperation with a physics teacher I developed an instruction unit on "Energy, Work, Power, Force" (see DUIT, v. ZELEWSKI, 1978) for grades 7 and 8[1]. During the development and evaluation of the unit we were quite pleased with the outcomes, we were convinced that we had done a nice job. But there were some evaluation data indicating difficulties of the students in overcoming preinstructional notions. When explaining simple processes, for instance, they prefered notions stemming from everyday experiences. Very seldom they applied the energy concept (especially the principle of energy conservation) to such processes.
My concern with notions about the energy concept, therefore, has not been primarily motivated from a special theory of cognitive development. It was the interest of a person engaged in physics education which guided my studies in this area.

The studies presented here are concerned primarily with students of grades 6 to 10. My general aim for these students with regard to "energy education" reads as follows: "Doubtless sufficient energy supply is among the most urgent problems in the future of the students and doubtless, too, physics instruction has to provide the students with some insight into this problem". Starting with this general aim many questions arise, some of the most important being:

(1) What is the contribution of physics instruction in this area? Does the physical concept of energy really provide students with an insight into problems of energy supply or do some aspects of this concept hamper such an understanding?

(2) What are the conceptions of energy stemming from the use of this concept in daily life that students bring into physics instruction? Do such conceptions ease or hamper the learning of the physical energy concept?

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1) *This unit is part of the IPN Physics Curriculum for grades 5 to 10. Energy serves as a guideline of this curriculum.*

(3) Is it possible to learn during physics instruction (e.g. in grades 7 to 10) those conceptions which promote an understanding of energy supply?

I am sorry that it is not possible to deal with all these questions sufficiently in this paper. But they form a frame for the following sections and some answers will be given.

Finally a remark on possible interests of the readers. This paper attempts a compromise for those who want to know something about conceptions of the energy concept and those who are mainly concerned with the method used in the study. I hope both will find their interests sufficiently taken care of in the paper.

2. BASIC ASPECTS OF THE ENERGY CONCEPT AND THEIR SIGNIFICANCE FOR ENERGY EDUCATION

Considerations of the question "Which aspects of the physical concept of energy can help the students to get some insight into the problem of energy supply?" have resulted in the following basic aspects.

(1) Energy as a quantity
This aspect is often delineated when speaking of energy as precondition (or even ability) for doing work or doing a useful job in general. Energy is "something" being able to bring about changes in the world. Energy is a special (a very general) kind of fuel[1]. Although I tried to give a somewhat conspicious notion of what is meant with the aspect of "energy as a quantity" it should not be overlooked that in physics a very abstract idea is meant[2].

(2) Energy transfer
The abstract quantity being able to bring about changes or to perform a useful job (or just work) can be transferred from one system to another (from one place to another).

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

1) *see e.g. ROGERS, 1965.*

2) *see e.g. FEYNMAN, 1969.*

(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. Energy conservation is a basic principle of physics.

(5) Value of different energy forms
When speaking about energy one can't avoid to speak explicitly, or implicitly about entropy too. For the purpose of introducing energy in lower grades (e.g. grades 7 to 10) we have to restrict ourselves to a very simple notion of entropy. When energy is converted in a process the amount of energy is conserved. But although the amount of energy has not changed the "value" of energy may have decreased. We then can't use the energy to run the same process once more. The different energy forms are of different value.

Which of the basic aspects of the energy concept are needed for the above mentioned insight into problems of energy supply? I think the students should get some idea of all five aspects.

It is obvious that the students should know something about the aspect (1) that is to know that energy is needed to run our machines or for life in general (energy in food). It is obvious, too, that some knowledge about energy transfer (2) and energy conversion (3) is needed. To answer the question whether the aspect of energy conservation (4) can contribute to an insight into problems of energy supply is not as 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 point of view of the above mentioned general aim of teaching energy in school. It is easier to answer why the students should know something about the value of different energy forms (5). The first reason has to do with the fact that the notion of energy conservation may hamper an understanding of sufficient energy supply. The student may wonder why there is a problem of energy supply when energy is not lost (is conserved). The second reason has to do with the insight of researchers in the area of energy supply that the most important task in this area is not only to save energy but to minimize energy devaluation (energy degradation).
These few remarks on the significance of the basic aspects for "energy education" must do here. We will come back to the aspects when discussing results of the studies.

3. METHODS OF THE STUDIES

For the purpose of the studies a questionnaire has been developed. Sometimes the information gained from explanations in the questionnaire has been enriched by interviews.

The questionnaire contains two parts (see fig. 1).

The first is focussed on the meaning of the words (the concepts' names) energy, work, power and force. The second part is restricted more or less to the application of the principle of energy conservation in simple processes of mechanics.
When the 5 basic aspects of the energy concept are concerned there is a focus on aspect (4) although the other aspects are taken into consideration, too, especially in the evaluation and interpretation of part 1.

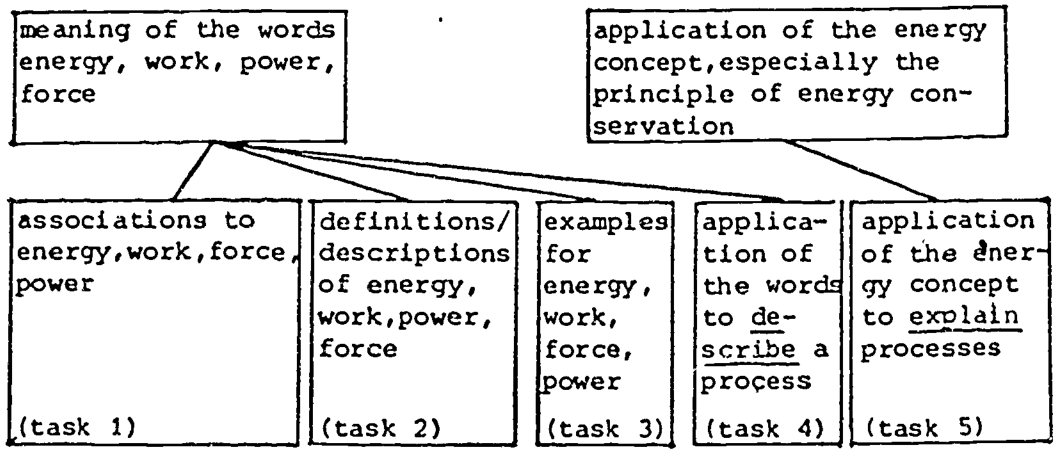

Fig.1: Overview of the questionnaire

The questionnaire and some evaluation categories are contained in the appendix of this paper. This section will present a brief overview.

3.1. Overview about part 1 of the questionnaire

The meaning of the words energy, work, power and force is investigated in different aspects (see fig. 1).
Associations provide us with information about ideas coming into the minds of the students more or less spontaneously i.e. without "logical" thinking about the concepts. This method has been used

by several authors[1]. Some of them (e.g. Shavelson and Preece) wanted to detect relationships between content structure and cognitive structure.

In the questionnaire discussed here I am interested in differences between associations of different words and in differences between associations of the same word at the beginning and at the end of the learning process (i.e. at the beginning and the end of an instruction unit). Therefore, the same scheme of categories is used for every word[2]. Differences of the percentage in categories are the basis for the interpretation.

The associations give us some information about ideas coming into the students' mind when confronted with words we use in physics as names for concepts. Definitions bring us a little nearer to the "logical thinking" of the students in this area although one can't distinguish whether a definition is based on "understanding" or is merely learned by heart.

Examples for the concepts give information somewhat between associations and definitions[3]. The same scheme of categories as in task 1 is used for evaluating the data.

Another aspect is payed regard with the application of the words to describe a process (an electrical motor connected with a battery lifts a weight, see task 4 in the appendix). This task gives some hints whether the students are able to make use of the concepts.

Of course, the results of tasks 1 to 4 don't provide us with a comprehensive insight in 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 partly. For a more comprehensive insight tasks for application had to be included in the questionnaire.

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1) *see e.g.: SHAVELSON, 1974; PREECE, 1977; SCHAEFER, 1976 and 1980; WEST, 1980; COCHAUD, THOMPSON, 1980; JUNG, 1981.*

2) *The categories are contained in the appendix of the paper.*

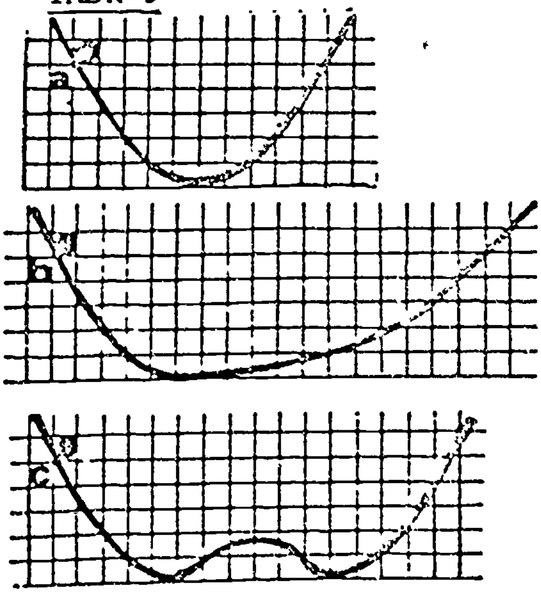
3) *The ability to give examples for a concept is of significance in learning theories like the approaches of GAGNE (1970) and KLAUSMEIER (1974). GILBERT and OSBORNE (1979, 1980) have worked out a method of investigating students conceptions based on examples and non-examples for a concept.*

3.2. Overview about part 2 of the questionnaire

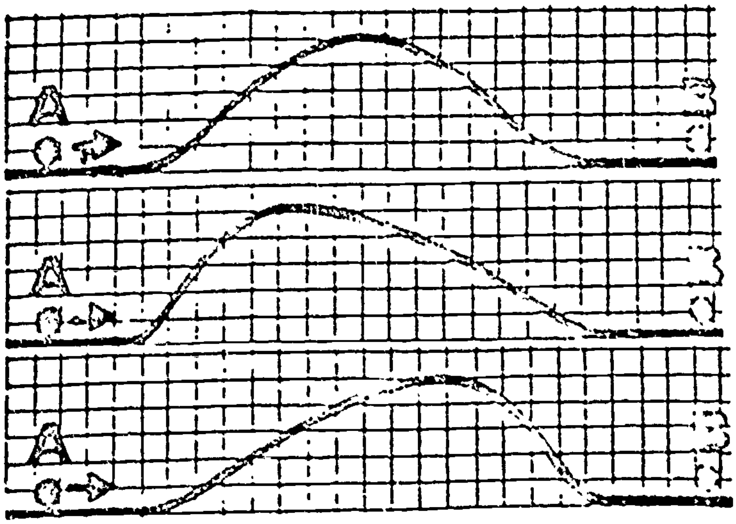
The tasks of this part focus at the application of the energy concept (especially the principle of energy conservation) to explain "simple processes".

The first two tasks are concerned with the motion of a ball rolling without friction and without drive of it's own in curved pathes and over slopes of different shapes[1].

TASK 5



TASK 6



In task 5 the ball is released at spots a, b and c. In task 6 the ball is passing spot A with a speed being great enough to go over the slopes. In task 5 the same height is reached in task 6 the speed at spot B is as great as the speed at spot A. The students are asked for a prediction of the height or the speed of the ball and for an explanation of the prediction. The purpose of these tasks is to find out whether the students are able to apply the energy concept and especially the principle of energy conservation or whether they make use of noticns gained from everyday experiences.

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1) *The idea of these tasks I owe DAHNCKE (1973). The taks have been used in several studies already (see e.g. DAHNCKE, DUIT, v. RHÖNECK, 1981; DUIT, 1981; JUNG, WEBER, WIESNER, 1977; WOHLENBERG, 1976).*

TASK 7

In another task (task 7) a car is loaded in a first trial with the driver only. It starts rolling down a hill without any drive by the motor and comes to a rest at point A of the horizontal path. In the second trial the car is loaded with 5 persons. It starts rolling at the same place as in the first trial and rolls down the hill without any drive by the motor, too. Friction is no longer neglected.

The students are asked to mark the spot the car will reach in the second trial and to explain their prediction.

The three tasks (5, 6, 7) are supposed to reveal the ability of the students to apply the energy concept (especially the principle of energy conservation) to "simple" problems. The insight they offer is, of course, limited in more than the following two aspects. Firstly, the problems are restricted to mechanics and secondly they are quite artificial. The students are asked for predictions (e.g. height or speed of the ball in task 5 and 6). If the students chose a right answer we might take this as hint that the students use the notion of energy conservation[1]. The explanation the students give to their predictions and interviews on this point out very clearly that this is not true in any case. There is a remarkable number of students giving right answers yet offering an explanation in the framework of everyday experiences and not in the framework of energy conservation. We will have some results on this later.

I am interested, therefore, not so much in the predictions of the students but in their explanations. I want to know whether

1) *DAHNCKE (1973) does so in using many such situations (e.g. pendulum, too).*

the students make use of concepts they learnt in physics instruction or whether they are still using conceptions stemming from everyday experiences even after physics instruction.

3.3. Comments on part 1 and part 2 of the questionnaire

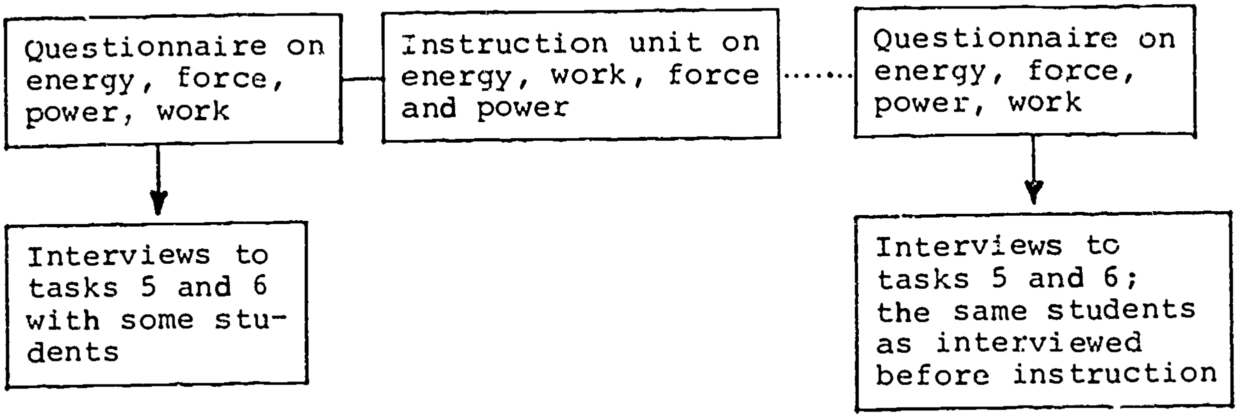
Some concluding remarks on the questionnaire with regard to the above stated general aims of my studies are recessary. If one imagines the 5 basic aspects of the energy concept (see section 2 of this paper) the information gained from the questionnaire is limited. The students have of course the opportunity to mention all basic aspects in tasks 1 to 4. But the results of these tasks only tell us whether the students mention an aspect spontaneously. If we want to get more information about the students' knowledge especially to single ones of the five basic aspects we would have to include further tasks going more straightforeward to the students knowledge.

The questionnaire presented here is a compromise between my interests and the patience of the students. In grades 6 to 10 the students are hardly able (though mostly willing) to answer all the questions in the 45 Minutes of a lesson in German schools. Other studies, therefore, have to answer the questions which can't be payed attention to here.

3.4. Use of the questionnaire

The questionnaire presented in section 3 of this paper has been used in several studies. It was not exactly the same in all of these studies because the gained experiences were enployed to develop the instrument. In this paper some results from two studies will be given. The first (study A) deals with learning of the energy concept during an instruction unit "energy, work, force and power" in grades 7 and 8. The second(study B) is looking more generally for the outcomes of physics instruction during grades 6 and 10 with regard to the energy concept.

Study A



The same questionnaire was used before and after instruction. Before instruction and after instruction as well some students were asked in interviews for some further explanation to their answers given in the questionnaire to tasks 5 and 6 (and another task not presented here as well). This combination of questionnaire and interview seems to be fairly fruitful because data from a great number of students are gained with the questionnaire whereas the interviews obtain the conceptions of some students in more detail. The interviews therefore promote the interpretation of the explanations given in the questionnaire too.

Study B

Philippino Elementary School (grade 6) High School, Manila (grade 10)	grade 6 (87 students)	grade 10 (89 students)
German High School (Gymnasien) Kiel	grade 6 (147 students)	grade 10 (170 students)
High School in Switzerland Basel	grade 7 (76 students)	grade 10 (124 students)

This study wants to detect differences caused by some years of physics instruction. The sample in Switzerland

(Basel)[1] provides a control test because there is not any physics instruction in High Schools (Gymnasium) before grade 10. The questionnaire was presented in the very first weeks of grade 10. The students had learnt in physics instruction nothing else than kinematics (motions, velocity). The Philippine students[2] and the German students were confronted with the questionnaire at the end of grade 6 and the end of grade 10

4. CHANGE OF NOTIONS DURING AN INSTRUCTION UNIT

Results from study A (see section 3.4.) are presented here. The sample contains 3 classes (84 students) grade 7 of a German High School. Instruction was based on the same unit about "energy, work, power and force" (see DUIT, v. ZELEWSKI, 1978) in all classes. Fig. 2 may illustrate the set up of the unit.

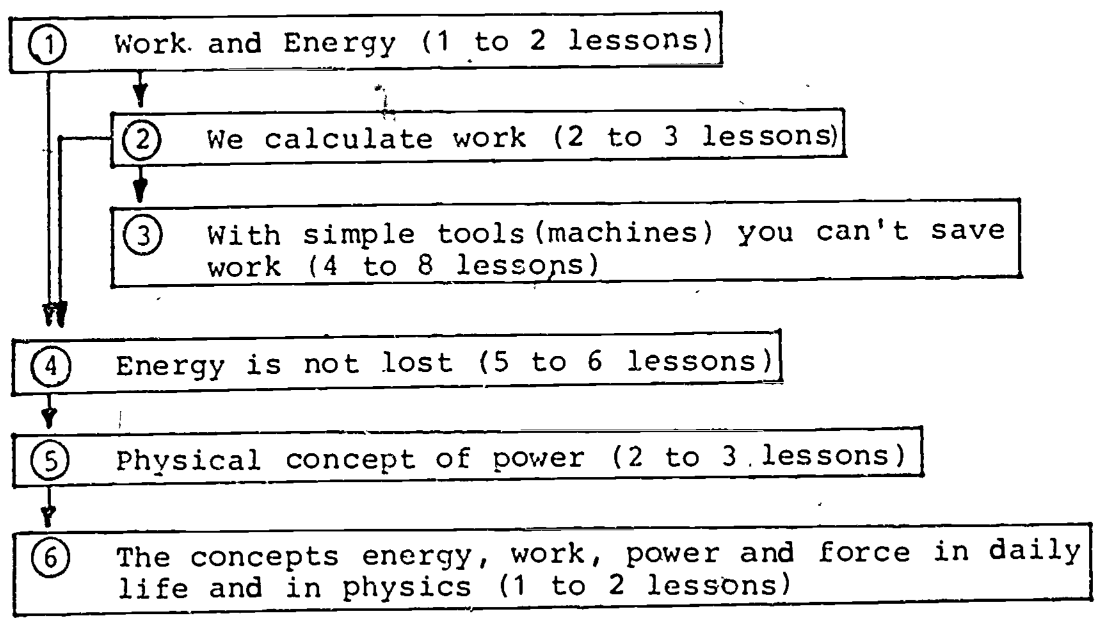


fig. 2: Set up of the instruction unit on energy, work, force and power used in the study of this section.

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1) *My friend Hans Brunner was so kind to organize the study in Basel.*

2) *This part of the study has been carried out during a stay at the Science Education Center of the University of the Philippines in the beginning of 1981 as part of a cooperation between the IPN in Kiel and the mentioned Center in Manila. Very many thanks to Prof. Dr. Dolores Hernandez the director of the institute for facilitating my stay and to Dr. Vivien Talisayon and Genelita C. Balangue for the cooperation in this study.*

The questionnaire described in section 3 has been presented before instruction and 2 month after instruction as well. The same subsample of 15 students has been interviewed before and after instruction.

4.1. Students' notions about energy before instruction

We will be concerned here with some of the results obtained from part 1 of the questionnaire.
The list of the most frequent associations to "energy" (see fig. 3) may serve as starting point.

Associated word (English translation in brackets)	percentage of students mentioning this word
Strom (current)	46
Kraft (force)	21
Atomkraftwerk (nuclear power plant)	20
Kraftwerk (power plant)	15
Energiekrise (energy crises)	10
Kohle (coal)	8
Leistung (power)	7
Ausdauer (endurance)	7
Lampe (lamp)	7

fig. 3: Associations to energy, the most frequent words (3 classes, grade 7, n = 84)

It is remarkable that nearly 50% of the students associate the German word "Strom" (current) when asked for associations to energy. This points out already that energy is related for these students somewhat to electricity and current. We will have some more results which stress this fact.[1] When looking, for instance, at the most frequent words associated to "Strom" (current) we find energy among the most frequent words (29% of the students write down energy there).
Another point may be of interest, namely the relation between energy and force. We do not only find force among the most frequent associations to energy (see fig. 3) but also energy among the most frequent associations to force (20% of the students).

1) *In German everyday language (especially in mass media) Strom (current) ist very often used in the meaning of a special kind of fuel.*

The frequency list as presented in fig. 3 does only contain a little number of all the words associated by the students. To get a somewhat more comprehensive insight in all associated words we will, therefore, have a look to all words classified according to the categories presented in the appendix of this paper.

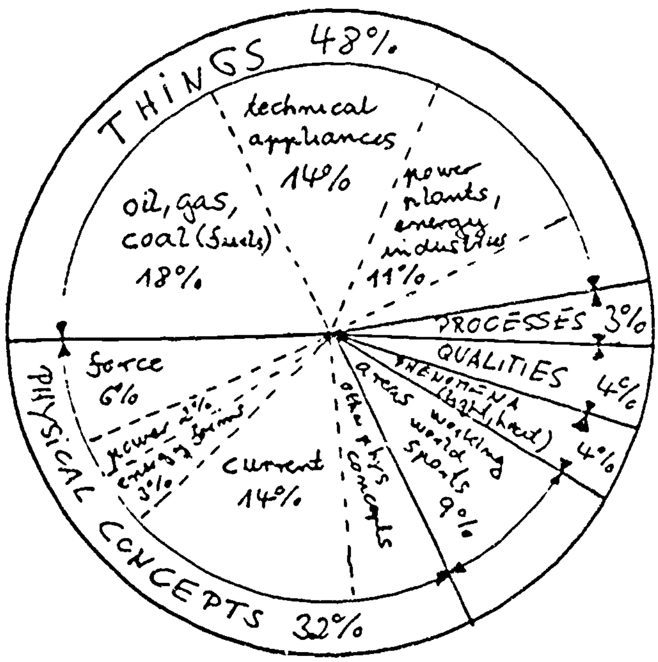


fig. 4: Associations to energy before physics instruction (Percentages of categories based at all given words)

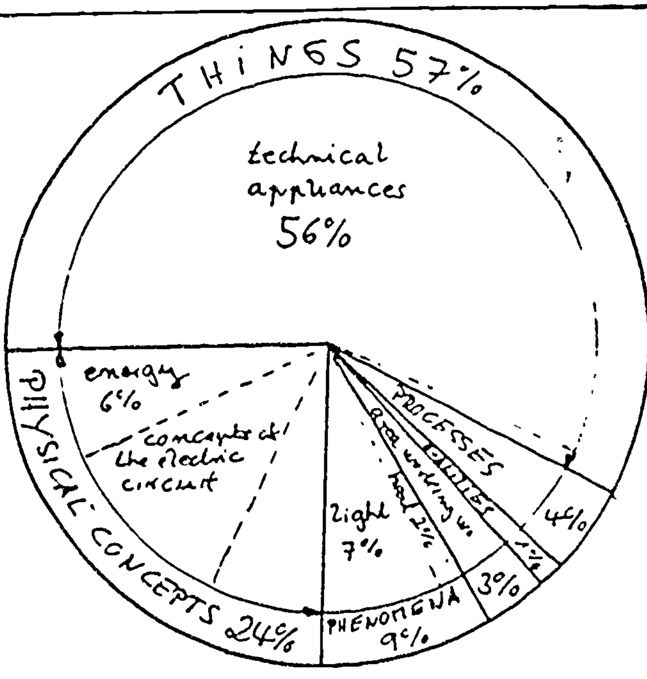


fig. 5: Associations to current before physics instruction

The associations to energy (see fig. 4) point out once more the close linkages between energy and electricity[1] (14% "current" among the "physical concepts" and 11% "power plants"). Furthermore a remarkable part of associations are classified under fuels (coal, gas, etc.).

The associations to the word Strom (current) are quite different (see fig. 5). More than 50% of the words could be classified as technical appliances (very often such used in the households).

The connections between energy and force are enlightened by comparison of fig. 4 and fig. 6. When taking into consideration that power plant may be associated because of a direct association to the word Kraft (in German language power

1) *Please notice that the percentages for current in fig. 3 and fig. 4 are different. In fig. 4 the percentages are calculated on the basis of all given associations whereas in fig. 3 the percentages indicate the number of students presenting a word.*

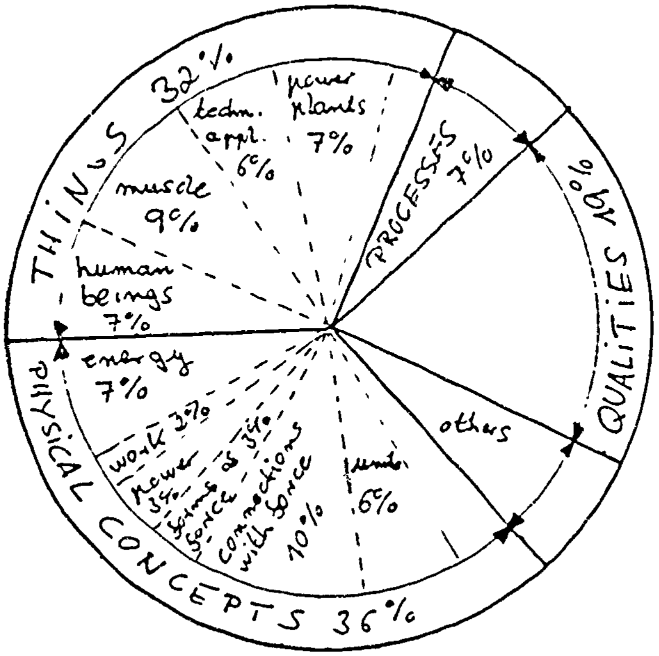


fig. 6: Associations to force before physics instruction

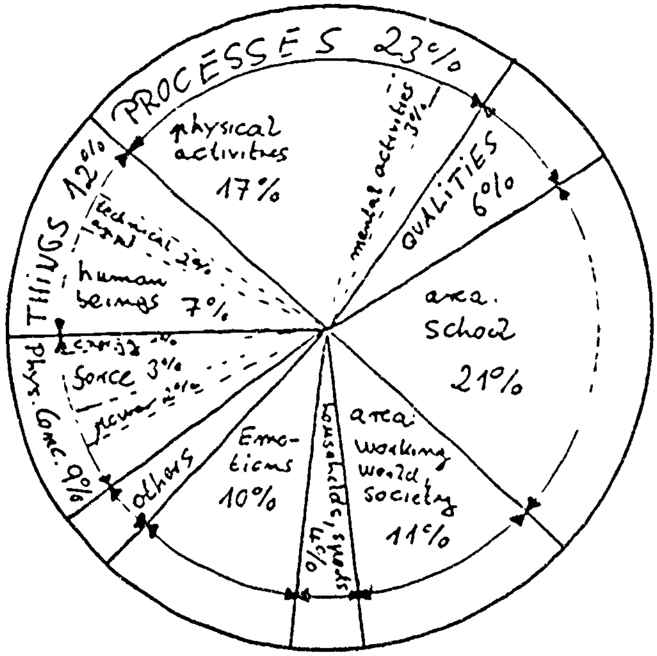


fig. 7: Associations to work before physics instruction

plants are called Kraftwerke, the verbal translation would be "force plants") many "things" associated to force are linked with human beings. Furthermore force is much more related to qualities than energy.

With regard to the fact that many textbooks all over the world try to introduce energy via work it may be interesting to look at fig. 7 presenting the associations to the word work. Remarkable is the total different structure of fig. 4 and fig. 7. Wheras energy is related to a great percentage to "things" this is not true for work. Especially the great number of associations classified into the categories "areas of school, working world, society, households, sports and emotions" point out difficulties when beginning energy education with the concept of work.

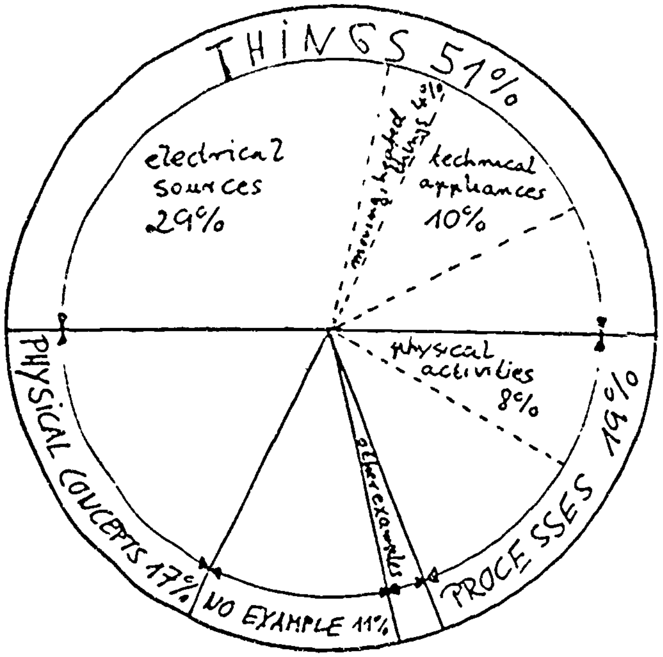


fig. 8: Examples given for energy

To enlarge the obtained insight into the meaning of the word energy for students in the above mentioned three classes the examples given for energy and force (task 3) are presented in fig. 8 and fig. 9.

Very many examples given for energy are related to electricity (not only 29% electrical sources like battery, dynamo and power plant have to be taken into consideration but also a number of processes classified under "other processes" which are related to electrical appliances). The overwhelming majority of examples for force are related to physical activities.

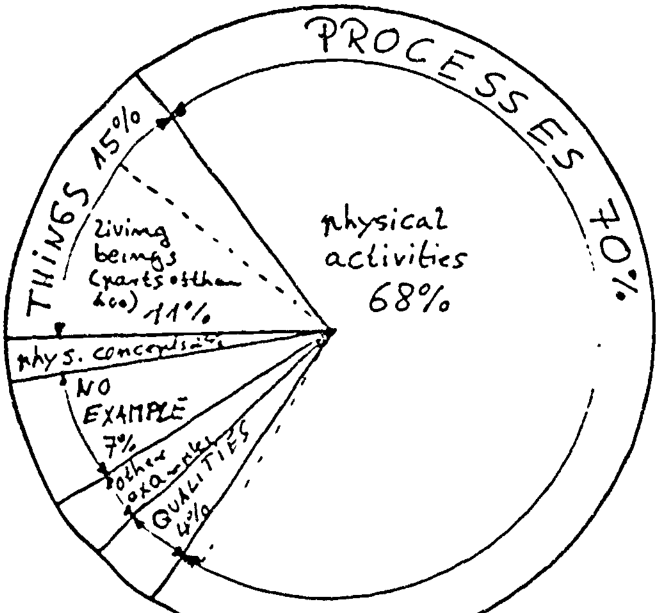


fig. 9: Examples given for force

Although some more details from tasks 2 and 4 could be added here to delineate the notion of energy I want to summarize. Energy is remarkably closely linked with electricity (current)[1]. This may be an interesting finding when considering that some introduction into the energy concept are restricted to mechanics only. Energy is also closely linked with fuels. When the relationships of energy and force are concerned the results point out that the notions about the two concepts are quite different although there is a confusion in using the words energy and force very often. Energy seems to be, for instance, a more general concept wheras force is restricted very often to mechanical processes only.

4.2. Change of notions about energy during instruction

Associated word (English translation in brackets)	percentage of students mentioning this word
Strom (Current)	32
Kraft (force)	21
Bewegungsenergie (motion energy)	18
Wärmeenergie (heat energy)	15
Energie sparen (save energy)	14
Höhenenergie (height energy)	14
Arbeit (work)	13
Wärme (heat)	12
Leistung (power)	10
Energieverbrauch (consumption of energy)	10

fig. 10: Associations to energy, the most frequent words (3 classes, grade 7, n = 84)

The list of the most frequent words (please compare fig. 10 with fig. 3) points out that there seems to be no general change

1) *The linkages between energy and current in German language are probably of greater significance for the introduction of the physical concept of current than for the introduction of energy. Current is for German students before physics instruction a kind of substance which is able to run very many machines in our environment (e.g. in the households). Current is, therefore, somewhat comparable to a fuel, it is closely related to energy. In physics current is "nothing but the flow of electricity" a notion not at all contained in students' conceptions. Therefore problems will arise when the teacher tries to introduce the concept of current. He speaks of current meaning flow of electricity. The students hear current, having a "special kind of fuel" in minds.*

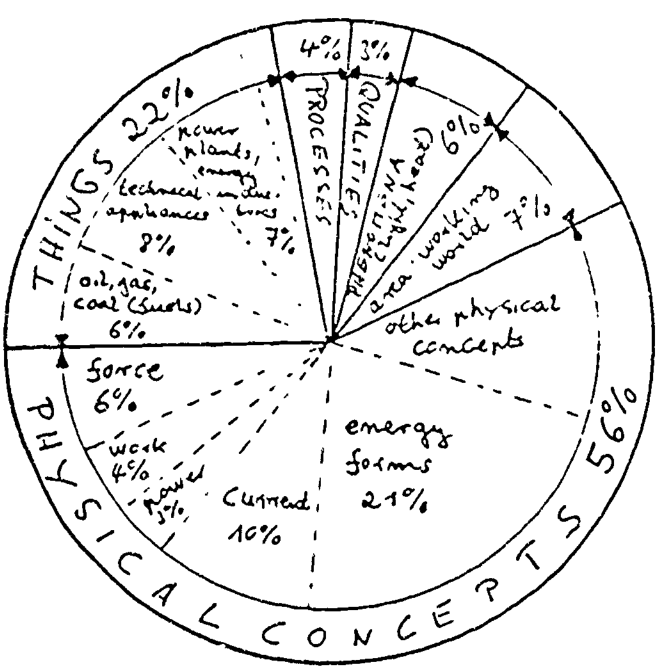


fig. 11: Associations to energy after instruction

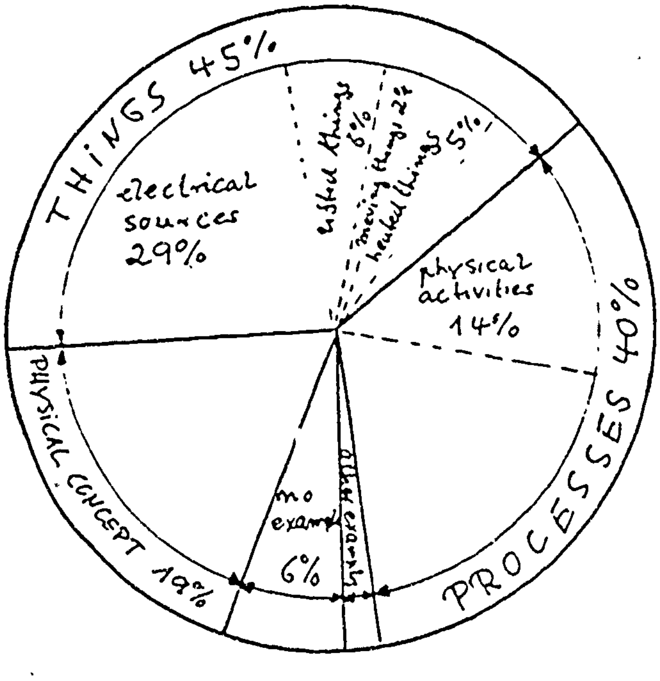


fig. 12: Examples for energy

in the associations to energy. Current and force, for instance, still are number 1 and 2. The most remarkable change has to do with the high frequency of energy forms (like motion energy) and words from energy economy ("save energy" and "consumption of energy"). Remarkable too, with respect to the setup of the unit is that work is among the most frequent words. The very first impression of fig. 10 is enriched by the diagram of fig. 11 in which all associations are included. It is interesting here, too, to compare this diagram with the diagram before instruction (see fig. 4). The general trends obtained already from fig. 10 are supported. The most remarkable change between fig. 4 and fig. 11 concerns the increase of energy forms. The increase of the word work seems to be comparably low (4% of all associated words only).

The results for examples given to energy (see fig. 12 and compare with fig. 8) strengthen the impression that the general notion of energy has not changed basicly during instruction.

The descriptions given for energy (task 2) may enrich the interpretation given by the results until now. There are only some result worth mentioning here:
In describing what energy is
- 17% of the students mention work after instruction (before only 4%) (e.g. energy is the ability to do work or energy is stored work).
- the precentage of students mentioning force decreases (30% before, 12% after instruction)

- energy forms are used by 15% within their descriptions (before only 2%).
- discouraging is the very small percentage of students mentioning the aspects of energy conversion, energy transfer and energy conservation after instruction (about 5%).

One can, therefore, state that the students in study A have not changed their notions about energy during instruction very much. With regard to the five basic aspects of the energy concept it is discouraging how limited the conceptions even after instruction are[1].

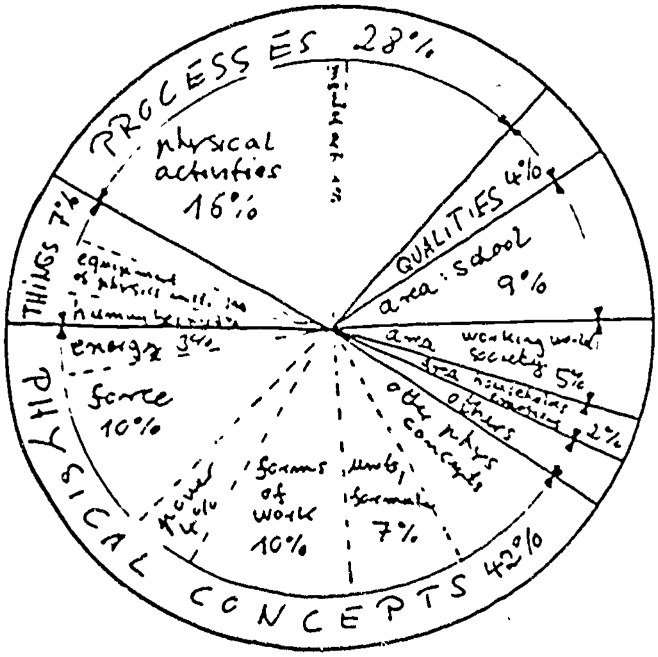


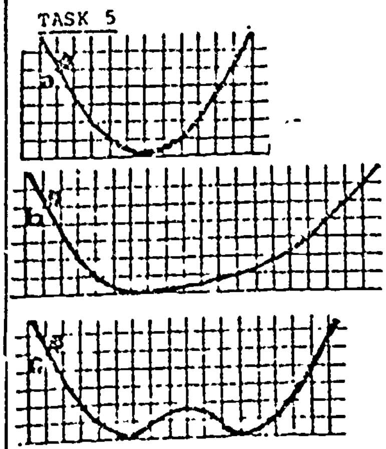
fig. 13: Associations to work after instruction

However, Fig. 13 presents the associations for work. Compared with the associations before instruction (see fig. 7) there are remarkable differences. The areas of "emotions, households, working world, school" shrunk very significantly whereas the category "physical concepts" expanded.

1) *Observation during the teaching of the unit in school seems to point out that the conditions of learning may mainly be responsible for the results. The students were taught only ore lesson a week and two classes were taught by a very less experienced teacher.*

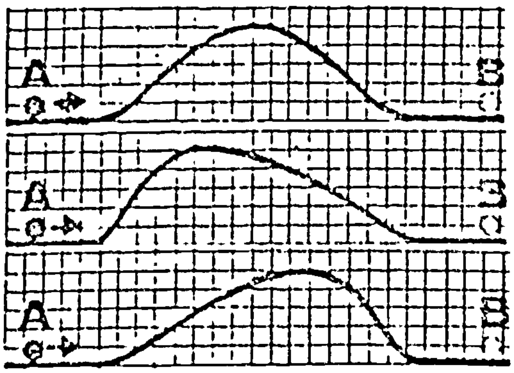
4.3. Application of the energy concept (part 2)

We will be concerned here with results of tasks 5 and 6[1].



	prediction of correct heights		explanation using energy		explanation using energy conservation	
	before	after	before	after	before	after
	13	55	2	17	-	8
	4	33	1	14	-	8
	5	37	2	12	-	10

fig. 14: Results for task 5 (84 students grade 7 before and after instruction); figures give percentages



	prediction of correct speed		energy used		energy conservation used	
	before	after	before	after	before	after
a	43	63	-	10	-	7
b	14	36	-	10	-	4
c	8	31	-	8	-	5

fig. 15: Results for task 6 (84 students, grade 7, before and after instruction); figures give percentages

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1) *Task 7 was not contained in the questionnaire used in this sample.*

Looking at fig. 14 and fig. 15 we can state that there is an impact of the instruction unit on predicting the correct heights and speeds in tasks 5 and 6. But the increases are not sufficiently for the more complicated paths (5b, c and 6b, c). The number of students using energy for explaining their predictions is rather small and the use of the principle of energy conservation is worse[1]. We can state, therefore, that the majority of the students doesn't use the energy concept for explaining the presented problems. They prefer other concepts, mostly such used in daily life too. The students in Germany, for instance, prefer for their explanations in tasks 5 and 6 the word "Schwung" (the meaning of this word may be described by the words drive or motion).
One of the most astonishing facts when dealing with the impact of physics instruction on notions of students is that the students do not seem to gain faith in applying physical conceptions. They prefer notions gained from everyday experiences. This is true not only for the studies presented here but for many other studies in this area. I want to present one example for this.

One student still argues in task 5a (which is the easiest) with energy conservation; *"since there is no friction, i.e. no heat energy, the ball again attains the same height"*. However in task 5b (which is a little more difficult) he returns to explanations which he used before instruction already. *"The gradient of the slope on the right side is flatter than on the left. The path attaining the same height as (a) is longer. The ball does not reach the same height because it does not have enough force."*

What are the notions students use to solve the problems? Fig. 16 presents an overview of the percentages in explanations categories.

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1) *I pointed out already that the students did not met good learning conditions in this study. In other classes the number of students using energy and energy conservation is higher (in average about 15 to 20%) but the general features are the same in all classes in which the tasks were used. Therefore the presented results appear to be quite typical for students in this age level when dealing with such problems.*

	5a		5b		6a		6b	
1. Explanations concerned with the geometry of the path	29	17	73	54	27	35	49	46
steepness	23	10	67	45	14	14	30	31
length	4	-	17	27	5	4	18	19
compensation of steepness and length		-	2	7	1	1	2	7
symmetry/asymmetry	1	7	-	11	15	23	7	1
2. Used concepts								
drive, motion (Schwung)	79	57	63	43	54	44	38	42
force	8	6	10	5	5	4	2	1
energy	2	17	1	14	-	10	-	10
conservation of energy	-	8	-	8	-	7	-	4
work	-	1	1	4	-	1	-	1
3. there is no friction	5	48	-	27	-	9	-	7

fig. 16: Explanations given to tasks 5a, b and 6a, b (84 students, grade 7, before and after instruction); figures give percentages

Many explanations especially for the more complicated paths are concerned with the geometry namely with steepness, length and symmetry. We will look at such explanations for task 6 a little more in detail. There are students who predict in task 6 b greater speed and in task 6c smaller speed. The other way round there are students who predict in task 6b smaller speed and in task 6c greater speed. For these students the steepness and the length of the path are the variables determining the prediction. But the influence of the variables is seen by the two groups very differently. One group of students thinks that going uphill the long path (6b) is "drive - consuming" whereas the other group thinks that the high steepness (6c) is. Going downhill the steep path (6b) or the long path (6c) is attached to the ability of giving the ball much drive.

In the study presented here I used interviews to detect the notions of the students in more detail than possible by using the questionnaire only[1)]. I want to add two examples for such enrichments by interviews.
The first example deals with the striking fact (from the standpoint of a physicist) that there is a remarkable number of students predicting in tasks 6a, 6b and 6c an increase of speed. The interviews revealed that the notions of many of these students are not really clear and stable. One student, for instance, argued that it makes a difference in speed whether the ball comes down a slope already when passing spot A or comes along a horizontal path

1) *15 students (the same before and after instruction) were asked in interviews for more detailed explanations of their answers given in the questionnaire.*

(the same speed assumed at spot A). It seems as if the following notion influences the prediction of greater speed at spot B. The students put themselves in the place of the ball. When they have to go uphill they have to exert themselves. When they exert themselves a little going downhill, too, they have a greater speed at spot B than at spot A. Nonwithstanding that in the task it is pointed out that the ball has no drive of its own they concede the slope the ability to provide the ball with more drive than was used going uphill.

To get to know the "energy conceptions" of the students a little closer I included into the interviews the following thought experiment when students predicted in task 6 "greater speed" at spot B. I drew another slope - equal to the first one - into the questionnaire and asked for the speed after this second slope. After this I invited the students to imagine very many such slopes and to predict the behavior of the ball. Most students involved in this thought experiment were able to predict that the speed of the ball should increase (assuming that the speed increases going over the first slope). But some student were only willing to accept this increase for the first slopes. After passing these slopes speed will decrease they argued. Two other students tried to get rid of the consequences of the thought experiment (speed increases) by stating that in nature never 100 totally equal slopes will exist.

4.4. Summary of the result of part 1 and part 2

The results presented here indicate that the students had difficulties in learning the energy concept. Although there is a measurable impact of the instruction unit on answers to part 1 it seems as if the energy concept the student brought into instruction was not shaken basicly during instruction. From the standpoint of the aims of the unit (and from the standpoint of the basic aspects of energy as well) the limitations of the energy concept are discouraging. Especially the lack of a notion about energy conservation among the majority of the students is disappointing. The results of part 2 (tasks 5 and 6) indicate that in general the instruction unit had little impact on notions of the students. Very often the same notions arose before and after instruction as well. Sometimes a mixture of physical conceptions taught in instruction and "everyday" notions are visible[1]. It seems as if physics instruction very often is not able to overcome everyday notions and to strengther faith into physical knowledge. We will come back to this aspect later.

5. CHANGE OF NOTIONS ABOUT ENERGY DURING GRADES 6 TO 10

This section deals with results from "study B"described above. It is concerned with answers of students in the Philippines, in Germany and in Switzerland.

The curricula with special regard to energy for the samples in the Philippines and Germany read as follows:
Philippino students: grade 7: general science with a first introduction to energy, work, force, grade 8: chemistry, grade 9: biology, grade 10: physics (5 lessons a week, 45 minutes each): the concept of energy is introduced in "traditional" manner via the concept of work (energy is the ability to do work), the curriculum is not as "energy oriented" as the curriculum in the German classes.
German students: In grades 7 to 10 the students in Kiel get two physics lessons (each 45 minutes) a week. The curriculum is "energy oriented", energy is one of the guidelines of the official syllabus. In grade 7 an introduction into the energy concept is given (work and energy) in grade 8 one unit (about 15 lessons) deals with the relationships between energy, work, force and power. At the beginning of grade 10 the topic of energy supply (e.g. power plants) is taught What is actually done in physics instruction does not necessarily follow the mentioned official syllabus but to a greater extend the textbook used in class. However, most modern textbooks for this school level in Germany deal in some detail with the energy concept. Therefore, one can assume that this concept is given more time in the German classes of my sample than in the Philippino classes.
In Switzerland there is no physics instruction between the two presentations of the questionnaire.

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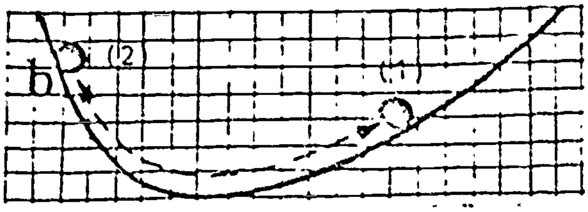
1) *I want to add an example for this. There are some students who predict that the ball will reach spot (1) when released but will go to spot b when rolling back. A student explained this prediction with energy conservation. He thought that the length of the path (not the height) is responsible for the converted energy.*



This student argued before instruction already with explanations in which the length of the path played an important role.

5.1. Change of notions as indicated by part 1

As many data have not been evaluated yet only some results can be presented here.

I want to begin with definitions (descriptions) given for energy in grades 6 and 10 (see fig. 17).

As far as the Philippine samples are concerned there is a significant impact of physics instruction. More than 60% of the students mention in grade 10 "work" in defining energy; 62% state phrases like "energy is the ability (or capability) to do work". But the usage of the word energy seems to be restricted to this sentence. Almost no student, for instance, mentions the aspects of energy conversion, energy transfer and energy conservation. Similarly in grade 10 of the German sample there is a great number of students mentioning work. But only some define "energy is the ability to do work". This difference could be caused by the way the energy concept is dealt with in these schools. Energy is not primarily introduced as "ability to do work" but rather as "precondition for work" or as "stored work", too, and energy is not restricted to mechanics but is worked out more generally including non - mechanical areas of physics.

The aspects of energy conversion and energy conservation is mentioned by about 10% when defining (describing) energy[1].

Although the impact of physics instruction seems to be higher for the German sample the number of students with false definitions is rather high. There are, e.g. about 6% of the population stating that energy is more or less the same as force.

When notions about energy as indicated by associations are concerned the same trends as described in section 4 are visible.

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1) It is important to point out that the German sample met better learning conditions than the Philippine sample. Furthermore in the German physics curriculum energy has been one of the guidelines, physics instruction has been more energy oriented than in the Philippines.

1. Mentioned concepts	Philippine schools gr.6	Philippine schools gr.10	German schools gr.6	German schools gr.10	Swiss schools gr.7	Swiss schools gr.10
WORK	9	67	3	42	8	6
- energy necessary for W.	-	5	1	21	4	3
- ability to do work	1	62	-	4	1	1
- en.is stored work	-	-	-	10	-	-
FORCE	7	7	18	14	32	35
- energy is force	3	2	9	6	9	15
POWER	9	13	1	7	3	4
CURRENT, ELECTRICITY	6	1	21	12	26	10
STRENGTH	19	10	3	1	5	2
2. Energy conversion and transfer						
Energy forms mentioned	4	3	3	12	4	3
Energy conversion	-	1	-	10	-	-
Energy transfer	-	-	1	1	-	-
Energy conservation	-	-	-	11	-	2
3. Energy is needed for...+)						
Technical appliances	3	-	12	10	18	11
Physical activities	23	6	3	3	3	6
light, heat	6	1	15	8	11	9
4. Energy is contained in...+)						
Fuels	-	-	5	4	5	11
food	2	1	-	-	3	1
sun, wind	2	5	5	1	4	2
power stations	-	-	10	1	13	5

fig. 17: Definitions for energy (grades 6 and 10)

+) Only some of the evaluation categories under these aspects are regarded here.

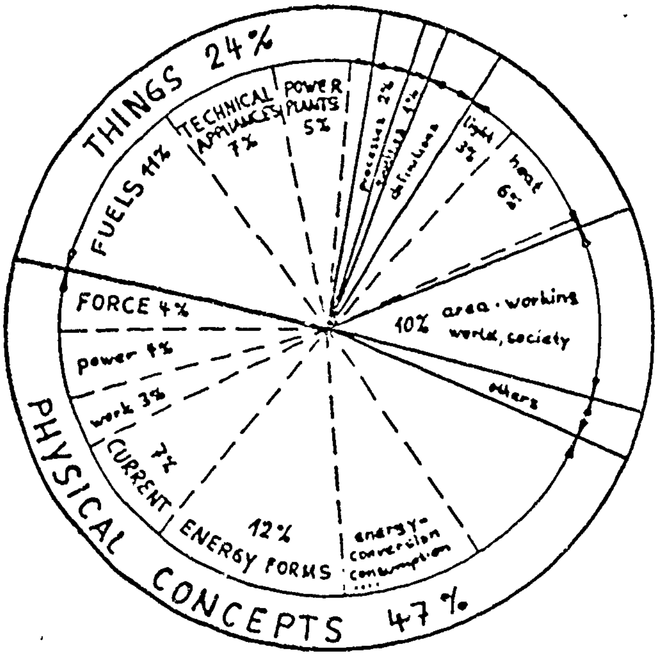

fig. 18: Associations to Energy; German High School, grade 10

There is a remarkable increase in physical concepts, especially energy forms and words linked with energy like energy consumption, energy conversion and others.
Interesting with regard to the method of association test is that the same general structure of the diagrams arise (compare fig. 18 and fig. 11).[1] Therefore, we can conclude that the method reveals some aspects of notions about energy among German students.
In the Philippines we find a different structure in grade 10 and grade 6 as well. Only a little number of associations are classified as things. This is true both in grades 6 and 10. Some other results seem to point out that there is a significant difference between the Philippine and German conception of energy especially in grade 6. Whereas energy for German students in grade 6 is closely related to fuels and electricity this is not so for students in the Philippines. For these students energy is more closely related to "strength". The German students seem to have endurance or something stored in mind when confronted with the word energy. These preliminary hypotheses will be examined in the next time considering further findings.

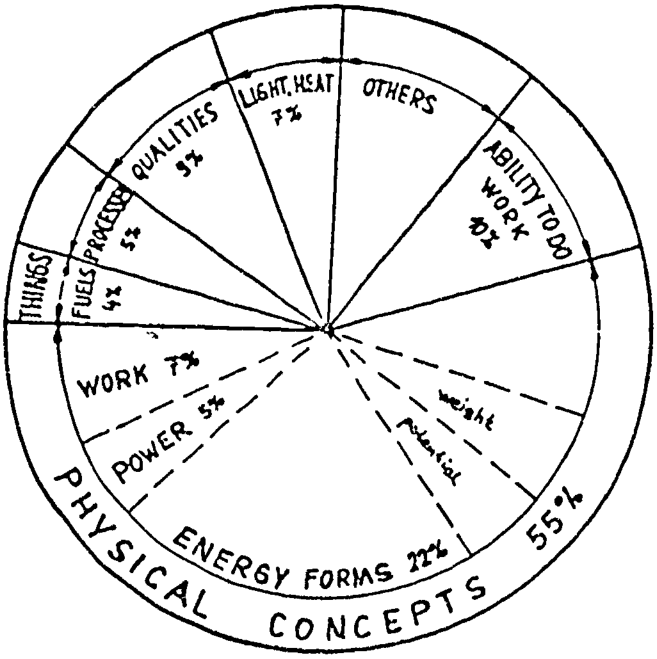

fig. 19: Associations to Energy; Philippino High School, grade 10

1) *In Switzerland, too, the same general structure is obtained.*

5.2. Application of the energy concept (tasks 5 to 7)

		German High School gr.6 n=147	German High School gr.10 n=170	Swiss High School gr.7 n=80	Swiss High School gr.10 n=124
TASK 5					
Prediction of correct height	5a	7	47	25	32
	5b	3	26	12	15
	5c	7	33	11	17
Use of energy for explanation	5a	1	35	3	6
	5b	1	26	1	6
	5c	1	22	-	4
Use of energy conservation for explanation	5a	-	26	-	3
	5b	-	18	-	2
	5c	-	15	-	2
TASK 6					
Prediction of correct speed	6a	41	75	45	56
	6b	20	35	13	28
	6c	13	31	14	23
use of energy for Explanation	6a	1	22	1	7
	6b	-	18	1	6
	6c	-	17	-	6
use of energy conservation for explanation	6a	-	16	-	3
	6b	-	9	-	2
	6c	-	9	-	2
TASK 7					
Prediction	car stops before A	11	18	9	8
	at A	9	12	5	16
	after A	58	59	70	66
use of energy for explanation		-	15	1	2
satisfactory explanation+)		1	12	3	6

fig. 20: Results for tasks 5 to 7 (see description of the tasks in the appendix of this paper). German and Swiss High Schools grade 6 (or grade 7) and grade 10. Figures give percentages.

+) An answer is classified as "satisfactory" when it is expressed that energy (or another equivalent quality) of the car increases and that friction does not increase or does only increase less than energy.

Fig. 20 presents results for tasks 5 to 7 of the questionnaire.[1)]

1) *Date from Philippine students have not been included in fig. 20 because in these samples there is almost no difference between grades 6 and 10 with regard to predictions and explanations as well. The curriculum being not so much concerned with energy may be responsible for this.*

The most important results of tasks 5 to 7 concerning the application of the energy concept are presented in fig. 20. When looking at the differences of correct predictions in tasks 5 and 6 between grades 6 and 10 we can state a substantial increase for the German sample, although the percentages for the more complicated paths are not at all sufficient. The results are similar to the above presented increases during an instruction unit (see figures 14 and 15). In contrast the Swiss sample shows a much smaller increase between grade 7 and grade 10.

What has been stated earlier when interpreting the results of learning the energy concept during instruction (see section 4.3. of this paper) is true here, too. The number of students using the word energy in their explanation is rather small. Most students still prefer after four years of physics instruction conceptions stemming from everyday experiences.[1] The conceptions which are to be seen among the students of grade 10 are more or less the same as those described for students in grade 7 (after an instruction unit about energy, see section 4.3. of this paper).

A few words to notions students use to solve the problems in task 5 and 6 maybe of interest. The description of some notions given in section 4 of this paper for students of grade 7 taught by an instruction unit is valid for all samples presented in this study (with slight modifications of course). The stock of notions to be found in the samples is more or less the same. This is true for the students in the Philippines, Switzerland and Germany as well.

Only some remarks on task 7 are necessary. The predictions are of less interest here. The percentages are nearly the same in grades 6 and 10.[2] The word energy is used only by a small number of students. Satisfactory explanations are offered only by a small number, too.

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1) *In evaluating this reluctance to use the energy concept one has to take into consideration that the questionnaire was presented in physics lessons and that is was pointed out several times that the tasks are concerned with energy.*

2) *There is a remarkable difference between students in Germany and Switzerland on the one hand and the Philippines on the other. Whereas the Swiss and German students prefer the answer "after A" the students in the Philippines prefer "before A" in grade 6 and grade 10 as well. I don't see an explanation for this at the moment.*

The results presented in this section (based primarily on fig. 20) point out that even a long period of physics instruction is hardly able to strengthen the faith into the energy concept among the majority of students.

6. SUMMARIES

6.1. Summary I: Notions about the energy concept

The results presented in this paper are obtained from samples with a rather limited number of students. Conclusions drawn from the results are valid primarily for the enrolled students. But as some findings are the same in all samples, these may allow some general conclusions about the energy concept.

6.1.1. Notions before physics instruction

For students in Germany and Switzerland as well energy is closely linked with electricity (current) and with fuels. Energy seems to be a very general kind of fuel. With regard to the physical energy concept there are some important limitations in this notion. Firstly, energy is more or less restricted to technical appliances, energy is a "fuel" for motors, machines etc. but energy is not (or very seldom) linked with food. Secondly, energy is not considered as basic precondition for all processes but is mainly associated with things that make our lifes more comfortable: energy is seen as a sort of luxury item. For a life without technical aids no energy would be needed (see DUIT, v. ZELEWSKI, 1978). Furthermore a notion of energy conservation is lacking. What happens to the general fuel "energy" after consumption is not considered. For students in the Philippines energy is not as closely related to electricity and fuels. Energy is seen very often linked with strength whereas in Germany and Switzerland energy is linked with endurance and with something (general fuel) stored. It seems as if energy for the Philippine students has a similar meaning as force (the German word is Kraft) for the German students.

As far as the meaning of the word "work" before instruction is concerned two important conclusions for physics instruction can be drawn. The everyday concept work is obviously very different from the physical concept. Especially associations from the areas "emotions", "working world, society" and "school" indicate problems in learning the physical concept of work. With regard to the learning of the concept of energy it should not be overlooked that energy and work are not at all linked with one another in the minds of the students before physics instruction. This will cause difficulties when introducing energy via work as practiced in most German approaches to the energy concept.

6.1.2. Change of notions during physics instruction

It is remarkable that physics instruction does not alter drastically the students' notions about energy. In part 1 of the questionnaire the same general structure (e.g. the same structure of associations as presented in the pie diagrams) is visible in grades 6 and 10. The notions expressed in explaining simple processes in mechanics are not basically different in grade 6 and grade 10. This is true for students in the Philippines and Germany as well.

The impact of physics instruction on notion about energy is limited. For the Philippine students this impact is restricted more or less to the "definition": energy is the ability to do work. In Germany physics instruction, too, causes a closer linkage between work and energy. But energy is not solely restricted to this concept. Some students mention the aspects of energy conversion and energy conservation. Such notions seem to be not present among the Philippine students.

On the other hand the energy concept gained during physics instruction is rather limited, even for German students. With regard to the five basic aspects of energy (see page 4) only a little number of students mention energy conservation (aspect 4). No student presented an answer which could be interpreted as notion about energy degradation (different value of energy forms, aspect 5).

The results from part 2 of the questionnaire reveal a lack of faith in physical knowledge among the majority of the students. Explaining simple processes of mechanics only a small number of students employed the word energy and the principle of energy conservation. Most students even in grade 10 prefered conceptions and notions stemming from everyday experiences[1].

6.1.3. Conclusions

I want to come back to the general aim of energy education within physics instruction stated in section 1 of this paper. If we want to provide students with some insight into problems of energy supply we have to be aware of the fact that physics instruction very often fails to contribute to this aim. The energy concept learnt during instruction is too limited. Some ideas to overcome the underlying difficulties shall be mentioned here.

- Energy should not be restricted to the ability to do work, energy should become - right from the start - a concept of a more general meaning (including not only processes of mechanics but processes in the areas of heat, electricity chemistry and others too).
- The traditional way to the energy concept via work causes severe learning difficulties. Therefore, it seems to be easier not to begin with work but to introduce energy without using this concept.[2]
- Energy conservation and energy degradation must be given more emphasis. Some proposals for the latter haven been worked out (see BACKHAUS, SCHLICHTING, 1980; SCHLICHTING, 1979; DUIT, v. ZELEWSKI, 1978).

6.2. Summary II: Some remarks on the methods of the studies

The methods of the studies are presented in section 3. The appendix contains the questionnaire and some evaluation categories as well. This section will be concerned with summarizing advantages and limitations of the employed methods.

1) *In very many studies dealing with students' notions and conceptions a lack of faith in physical knowledge is revealed. Very often physics instruction is not able to shake notions stemming from everyday experiences (see e.g. GILBERT, OSBORNE, 1980; JUNG, 1979; WARREN, 1979; VIENNOT, 1979).*

2) *There are several proposals to do so (see e.g. SCIS, 1971; ORPAZ, N., DORI, E., SHADMI, Y., 1979; JUNG et al., 1978; FALK, HERRMAN, 1979).*

6.2.1. Remarks on part 2 (tasks 5 to 7)

I want to begin with some remarks to part 2 of the questionnaire because this part seems to be less problematic than part 1. As already mentioned this part is restricted to mechanical problems (motions of a ball and a car). Apart from this limitation the tasks of this part seem to be more or less satisfying. Tasks 5 and 6 (motion of a ball in curved paths and over slopes) provide us with an insight into students' notions. This is true especially when the answers given in the questionnaire are complemented by corresponding answers given during an interview. In general, the combination of presenting such problems in a questionnaire and asking afterwards a small number of students for a more detailed explanation seems to be rather effective: an overview about the notions of a large number of students is enriched by a deeper insight gained from a small number. Thus, the interviews support the interpretation of results obtained from the questionnaire.

It may be interesting to compare the results concerning task 5 with results gained with another method. There is a study dealing with a ball rolling down an inclined plane and going up another carried out in "Piagetian manner" (PIAGET, SZEMINSKA, 1973). This problem is very similar to the problem of task 5. Going back to the answers of the students (as far as published) the same general features as in the studies presented here arise (see KUBLI, 1981; DAHNCKE, DUIT, v. RHÖNECK, 1981).

6.2.2. Remarks on part 1 (tasks 1 to 4)

I want to discuss at first one task after the other. Remarks on the combination of the tasks will follow.

Task 1: association test

What do we really know when we know something about the words coming into the students' minds when confronted with a stimulus word? There is an ongoing discussion about this problem (see, for instance, the papers contained in the proceedings of a conference on "Cognitive Development" in Leeds, ARCHENHOLD et al., 1980). Some of the problems are the following. If a student writes down a word (associates) we don't know why he is doing this, i. e. wo don't know anything about the linkages to the stimulus word. Furthermore we don't know anything about the meaning the student relates with the word at the moment of

association. If a student writes down force we don't know whether the physical or the everyday meaning is meant. To overcome these difficulties GUNSTON (1980) proposes to ask for a sentence containing the associated word and the stimulus word.
Another aspect is mentioned by JUNG (1981). When it is an aim of physics instruction to build bridges between the pure "artificial world" of physics and the real existing world than an increase of physical concepts among the associations may regarded as problematic One could argue with the same right that the words of everyday language should increase.

Considering all this one has to ask whether the results of association tests do reveal anything about conceptions of the students. COCHAUD, THOMPSON (1980) point out the benefit of results from association tests for the teacher when planning instruction. Indeed, it is worth knowing for a teacher that students may have something quite different in mind than the teacher when hearing a word used in physics as name for a concept. And indeed, it is important for a teacher to know that physics instruction may not change very much or not at all the students preconceptions. For a curriculum developer there are similar benefits

Task 2: definitions (descriptions) for concepts

The ability to write down a definition does not tell much about the concept gained by the students. One can learn a definition by heart without any understanding. There is another aspect of some significance here. Working on a particular task may cause some stress in the students. A student working at task 2 realizes that there are many other tasks still waiting for his answer. Thus, it may well be that he writes down as definition what is coming into his mind first. After having remembered one aspect (e.g. "energy is the ability to do work" or "work is force times distance") he hurries to the next task without pondering about whether his answer is complete or not. Therefore, it can't be overlocked that the definitions may reveal not much "logical thinking" but rather still more "associative thinking".

Task 3: examples for the concepts

Most of what has been mentioned for task 1 is valid here, too. Giving an example is a task with some "associative" character.

There is another difficulty with the interpretation of the examples presented. Many examples can serve as instances for more than one concept. *"A boy lifts up a weight"* may be regarded as example for force, energy or work as well (force: "force needed for lifting" or "weight has a force"; energy: "one needs energy to be able to lift up" or "the lifted weight has potential energy"; work: "lifting is lift work"). Without an explanation why an example is given there is an uncertainty about the aspect the student wanted to point out.

Task 4: application of energy, work, power, force to describe a process

Task 4 investigates the ability of the students to make use of the words work, energy, force and power to describe a simple process ("a toy crane lifts a weight"). Similar problems as described above have to be taken into consideration here. Firstly, the correct use of the words is not necessarily based on a correct understanding of the concept. Secondly, there are the same uncertainties of interpretation as in task 3 (see the instance "a boy lifts a weight" given some lines above).

6.2.3. Comment on part 1 as a whole

Until now objections have been discussed only for the isolated tasks. When trying to come to a judgement of the questionnaire as a whole one has to take into consideration that not the results of single tasks but results of all tasks should be regarded when drawing conclusions. The results of the single tasks support one another. If a certain trait is stressed by more than one task one can be more shure that this trait is indeed of significance. Examples for this use of results have been given in sections 4 and 5 of this paper.

6.2.4. Remarks on evaluation categories

When discussing problems of the methods it is important to mention also problems with the evaluation categories. Examples for such categories are contained in the appendix. One serious problem concerns the process of finding categories. As pointed out in the appendix in my studies this process was guided by general categories (for the associations thing - process - quality - relation), by the aims of the studies and by answers of students given in trial runs. The categories are primarily important with regard to the aims of the studies. Furthermore, they are of "empirical significance". This means that it is possible to classify the answers according to the categories and that the gained classifications make sense with regard to the aims of the study.

Concerning the objectivity of the evaluation. I want to add that a very detailed scoring directory has resulted a fairly high index of objectivity.After some training the author and another evaluator confirmed each other in more than 90% of all classifications. This figure may be agreed as sufficient for the purpose of the studies presented here.

7. REFERENCES

ARCHENHOLD, W.F., DRIVER, R.H., ORTON, A., WOOD-ROBINSON, C. (Ed.), Cognitive Development. Research in Science and Mathematics. Proceedings of an international seminar. Leeds: The University of Leeds, 1980.

BACKHAUS, U., SCHLICHTING, H.J.: Vom Wert der Energie. Naturwissenschaften im Unterricht - Physik/Chemie. Themenheft 3: Der Energiebegriff im Physik- und Chemieunterricht, 28, 1980, 377 - 381.

COCHAUD, G.A.M., THOMSON, J.J.: Sequencing science material for particular classes. In: ARCHENHOLD, et.al. (Ed.), 1980, 368 - 376.

DAHNCKE, H.: Energieerhaltung in der Vorstellung 10- bis 15jähriger. IPN-Arbeitsbericht 9. Kiel: IPN, 1973.

DAHNCKE, H., DUIT, R., v. RHÖNECK, C.: Methoden und Zwecke verschiedener Untersuchungen zur Erfassung der Vorstellungen von Schülern - die Bewegung einer Kugel in gebogenen Bahnen. In: DUIT, JUNG, PFUNDT, 1981.

DUIT, R.: Understanding energy as a conserved quantity. European Journal of Science Education, 1981.

DUIT, R., ZELEWSKI, H.D. von: IPN Curriculum Physik für das 7. und 8. Schuljahr. Unterrichtseinheit "Energie, Arbeit, Leistung, Kraft". Stuttgart: Klett, 1978.

DUIT, R., ZELEWSKI, H.D. von: Ohne Energie ist es düster in unserem Leben - Aufsätze einer 8. Realschulklasse zum Thema Energie. Naturwissenschaften im Unterricht - Physik/Chemie, 27, 1979, 161 - 164.

DUIT, R., JUNG, W., PFUNDT, H. (Ed.): Alltagsvorstellungen und naturwissenschaftlicher Unterricht. Köln, Aulis, 1981.

FALK, G., HERRMAN, F.: Ein moderner Physikkurs für Anfänger und seine Begründung. Konzepte eines zeitgemäßen Physikunterrichts, Heft 3, Hannover: Schroedel, 1979.

FEYNMAN, R.P., LEIGHTON, R.B., SANDS, M.: The Feynman Lectures on physics. Vol. 1. Reading, Massachusetts: Addison-Wesley, 1969.

GAGNE, R.M.: The conditions of learning. New York: Holt, Rinehart & Winston, 1970^2.

GILBERT, J.K., OSBORNE, R.J.: An approach to student understanding of basic concepts in science. University of Surrey: Institute for Educational Technology, 1979.

GILBERT, J.K., OSBORNE, R.J.: A method for investigating concept understanding in science. European Journal of Science Education, 1980, Vol. 2 No. 3, 311 - 321.

GUNSTON, R.:quoted by WEST, 1980.

JUNG, W.: Schülervorstellungen in Physik. Naturwissenschaften im Unterricht - Physik/Chemie, 27, 1979, 39 - 46.

JUNG, W.: Assoziationstests und verwandte Verfahren. In: DUIT, JUNG, PFUNDT, 1980, 196 - 222.

JUNG, W., WEBER, E., WIESNER, H.: Der Energiebegriff als Erhaltungsgröße. physica didactica 4, 1, 1977, 1 - 19.

KLAUSMEIER, J.H., GHATALA, E.S., FRAYER, D.A.: Conceptual learning and development - a cognitive view. New York: Academic Press, 1974.

KUBLI, F.: PIAGETs Methode des kritischen Interviews und ihre Bedeutung für die Reflexion des Physikunterrichts. In: DUIT, JUNG, PFUNDT, 1981.

ORPAZ, N., DORI, E., SHADMI, Y.:Physics teaching to disadvantaged: Why and How. The Physics-Chemistry-Project, Curriculum Center, Ministry of Education and Culture. Jerusalem, 1979.

PIAGET, J., SZEMINSKA, J. de: Le problême de la remontée d'une bille après une descente. In: PIAGET, J.: La formation de la notion de force. Presses Universitaires de France, Paris, 1973.

PREECE, P.F.W.: Development trends in the continued word associations of physics students. Journal of Research in Science Teaching, 15, 1977, 395 - 399.

ROGERS, E.M.: Physics for the inquiring mind. Princeton, New Yersey: Princeton University Press, 1965[7].

SCHAEFER, G.: Was ist Wachstum? In: SCHAEFER, G., TROMMER, G., WENK, K. (Hrsg.): Leitthemen 1, Wachsende Systeme, Braunschweig: Westermann, 1976.

SCHAEFER, G.: Inclusive thinking with inclusive concept- In: ARCHENHOLD et. al., 1980, 382 - 296.

SCHLICHTING, H.J.: Energy and energy waste: a topic for science education. European Journal of Science Education, 1, 1979, 167.

SCIS: Science Curriculum improvement study: Energy sources. Teachers' Guide. Chicago, New York: Rand Mc. Nally, 1971.

SHAVESON, R.J.: Methods of examining representations of a subject matter structure in a students' memory. Journ. of Research in Science Teaching, 11, 1974, 231 - 249.

VIENNOT, L.: Le raisonnement spontané en dynamique élémentaire. Paris: Hermann, 1979.

WARREN, J.W.: Understanding force. London: Murray, 1979.

WEST, L.H.T.: Towards description of the cognitive structures of science students. In: ARCHENHOLT et.al., 1980.

WOHLENBERG, J.: Der Arbeits- und Energiebegriff - eine propädeutische Einführung im Anfangsunterricht. Hausarbeit für die pädagogische Prüfung für das Lehramt an Gymnasien. Flensburg, 1976.

8. APPENDIX

8.1. Questionnaire on energy, work, power, force

8.2. Evaluation categories for the questionnaire

IPN - Institute for Science Education at the University of Kiel

- Physics Education Department / R. Duit / 1981 -

8.1. QUESTIONNAIRE ON ENERGY, WORK, POWER, FORCE

School:	Age:	Date:
Your last name:	First name:	

The concepts "energy", "work", "power" and "force" play a major role in physics and therefore in physics instruction, too. In the first part of this questionnaire we would like to find out something about your ideas of these concepts. All questions in this part refer to the four concepts "energy", "work", "power" and "force" as they are used in physics instruction and not as they are used in everyday language.

If you have not yet heard anything about these concepts in your physics class, give the ideas you have formed about them on your own.

---

1 When you hear or read a word, you usually associate other words which have something to do with the word you heard or read about. The following task concerns such associations. Seven physical concepts will be named (e.g. written at the blackboard) one after another. You have about 30 seconds for every concept in which to write down the words which come to your mind.

(1) ______________________________

____

(2) ______________________________

____

(3) ______________________________

____

(4) ______________________________

____

(5) ______________________________

____

(6) ______________________________

____

(7) ______________________________

____

2

It is not so easy to describe in a few words the meaning of the physical concepts energy, work, power or force.
Please try anyway to find another description for the meaning of these concepts in physics.
If you have not yet heard anything about these concepts in your physics class, give a description of the ideas you have formed about them on your own.

Description for ENERGY : ____________________

____

____

____

Description for WORK : ____________________

____

____

____

Description for POWER : ____________________

____

____

____

Description for FORCE : ____________________

____

____

____

3

Perhaps in task 2 you have had some problems in describing your ideas and notions about the four concepts. Maybe it is easier for you to give an example for every concept.
"Peter stretches an rubber band" may for instance serve as an example for work, "A new battery lights up a lamp" as an example for energy.
Please write down your own examples for "energy", "work", "power" and "force".

Example for ENERGY : ____________________

____

____

Example for WORK : ______________________________

____

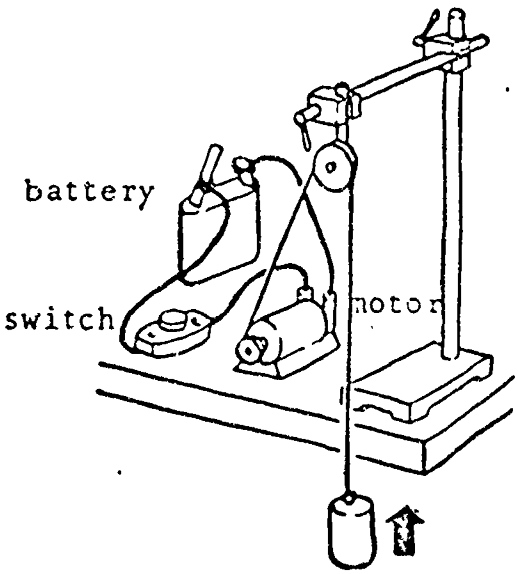
Example for POWER : ______________________________

____

Example for FORCE : ______________________________

____

4



The drawing shows a "toy crane". When the switch is closed, the "crane" lifts a weight. Please describe this process by using <u>each</u> of the following four concepts at least once: ENERGY, WORK, POWER and FORCE.

If you have heard something about these concepts in your physics class take the phy ical meaning. If you have not yet heard anything about these concepts use the ideas you have formed about them on your own.

____

____

____

____

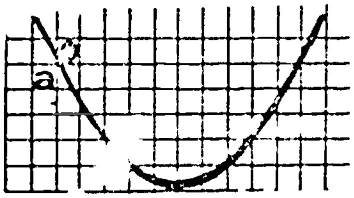
____

A T T E N T I O N : In the following tasks 5 and 6 a ball follows a curved path or takes it's course over slopes of various shapes. As the friction is very small in these motions we want to pretend that <u>there is no friction</u> at all. Friction is, of course, unavoidable in all motions in our surroundings, e.g. friction with the air, friction during rolling, or friction in the axles of a car.
In the following two tasks we will neglect all kinds of friction. <u>We want to pretend, that the ball is not decelarated by friction</u> of any kind.

5

In the three graphs, a ball follows a curved path. The ball is released at the marked spot and then rolls with no drive of its own. In all the experiments we want to pretend that there is no friction.

5a



Mark with (1) the spot you think the ball will reach before it begins to roll back! Give a short reason for your answer!

Reason: ____

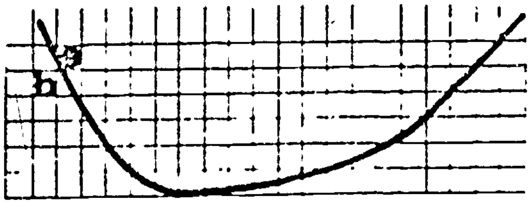
____

The ball das not remain at the spot you marked with (1). It rolls back along the curved path and reaches a spot at the other side of the path. Mark this spot with a (2). Give a short reason for your answer here too!

Reason: ____

____

5b



Once again mark with (1) the spot you think the ball will reach before it begins to roll back. Give a short reason for your answer.

Reason: ____

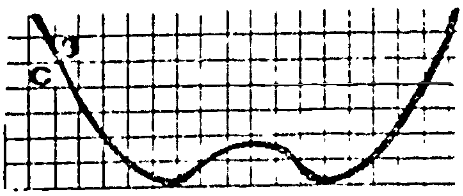
____

As in 5a , mark with a (2) the spot which the ball will reach when it rolls back from spot (1). Please give a reason.

Reason: ____

____

5c



Mark only with (1) the spot which the ball will reach before it begins to roll back. Please explain!

Reason: ____

____

6

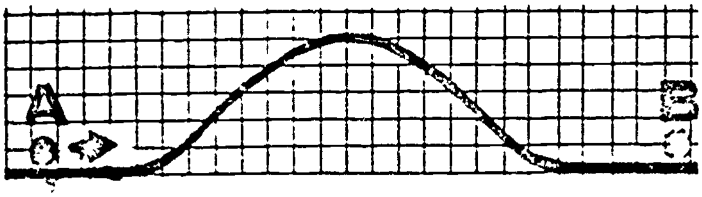
In this task our ball takes it's course over slopes of various shapes. The speed of the ball at spot A is always so great that it can go over the slope.

Again, the ball rolls without any drive of its own and we shall pretend that there is no friction.

Compare the speed of the ball behind the slope (at spot B) and in front of the slope (at spot A).

Put a cross next to the correct answer and give a reason!

6a



The speed of the ball at spot B is ....

greater than ( )
less than ( )
the same as ( ) ... at spot A.

Reason: ______________________________

____

6b

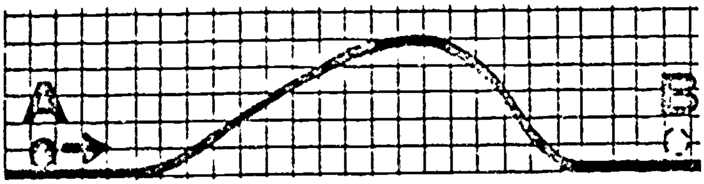
The speed of the ball at spot B is ...

greater than ( )
less than ( )
the same as ( ) ... at spot A.

Reason: ______________________________

____

6c



The speed of the ball at spot B is ...

greater than ( )
less than ( )
the same as ( ) ... at spot A.

Reason: ______________________________

____

7

The last two tasks were concerned with the motion of balls without any friction. We will now turn over to a motion with friction.

ATTENTION:	In this task you have to take friction into consideration. We don't pretend any more that there is no friction.

In a first trial a car is loaded only with the driver. It starts rolling down a hill without any drive by the motor and comes to a rest at point A of the horizontal path. In the second trial the car is loaded with 5 persons. It starts rolling at the same place as in the first trial and rolls down the hill without any drive by the motor, too. Where comes the car to a rest in the second trial? Please mark this point with a cross (X).

Please explain your answer!

That's the end of the questionnaire.

Thank you very much for answering our questions !

8.2. Evaluation categories for the questionnaire

Evaluation categories for part 1

The main problem with such tasks as contained in the first part of the questionnaire is to find categories for evaluating the answers of the students. These categories have to meet the aims of the study, they have to provide us with a comprehensive insight into the students answers and they have to facilitate an objective evaluation. Futhermore the evaluation does not become too time consuming. It is more or less an art to bring all these demands into a balance. The schemes of categories I worked out for tasks 1 to 4 are rather complicated. The description of them contains nearly 50 pages. Therefore, only a brief overview of the categories can be presented here. For the association test (task 1) the same scheme of categories is used for all concepts (see fig. 21).

1. THINGS

- *human beeings / animals / other things of nature*
- *technical appliances (tools in the households / motors, machines / battery, dynamo / vehicles)*
- *industrial plants or factories (e.g. power plants)*
- *equipment in physics instruction*

2. PROCESSES

- *activities (physical, mental activities)*
- *other processes (e.g. "a bulb glows up")*

3. QUALITIES (of things or processes)

- *(e.g. strength, fluid, hot)*

4. PHENOMENA

- *light, heat and others*

5. WORDS (CONCEPTS) FROM THE FOLLOWING AREAS:

- *school (e.g. examination, homework)*
- *working world, society (e.g. laborer, job, money)*
- *emotions (e.g. stress)*
- *household, leisure time, sports*

6. PHYSICAL CONCEPTS

- *Units / formula / terms*
- *energy / work / force / power and connections with these concepts*
- *specific categories for the single concepts*

fig. 21: Categories for task 1 (association test)

Starting point for the development of the scheme of categories as presented in fig. 21 has been the distinction between "things - processes - qualities - relations" which is of significance in philosophy as basic system of general categories. This general. system was not very well suited for the purpose of evaluating associations because in many cases one is hardly able to decide whether a given word (association) is meant as quality, relation or process. Therefore, modifications were necessary. Category 6 (Physical concepts), for instance, was included because I was interested in the physical concepts coming to the minds of the students when confronted with a word used as a name for a concept in physics.Of course, there is a fundamental difficulty with this category. If a student associates force when confronted with energy we can't be shure that the physical meaning of force is coming to his mind. It may well be that the meaning in everyday language is meant. Nonwithstanding this a word which is used in physics as name for a concept is classified as "physical concept".

In general the presented scheme of categories has only little philosophical significance but it is of more or less exclusively empirical significance with regard to the aims of the study.

The mere scheme of categories as presented in fig.21 will certainly not facilitate a sufficient evaluation of the given associations. A very detailed description of the categories is needed. As an example may serve the description for category 2 from my "evaluation directions".

Processes occurring in reality or which could occur in reality. Activities are such processes where work is being done (where something is done; work is meant here as word in everyday language). Physical activities: a physical exertion is needed (e.g.to lift up, to run, to pull). Mental activities: no such physical exertion is needed (e.g. to think, to learn, to read). A distinction is difficult in some cases because often both aspects are contained. If one aspect predominates it has to be chosen (e.g."to write" is classified under "mental activities" because the mental aspects predominates). If it is not possible to decide whether a physical or a mental activity is meant one classifies under "activities" (in general) only. ...".

The scheme of categories presented in fig.21 is not only used for evaluating the associations (task 1) but also for categorizing the examples for energy, work, force and power (task 3). For this purpose the scheme is somewhat simplified. For task 2 other schemes are used. For energy the categories are influenced significantly by the above mentioned basic aspects of the energy concept (see fig. 22)[1].

1. Mentioned concepts
   - work (ability to do work, stored work, energy conversion is work)
   - force (energy gives force / force gives energy / force is energy)
   - power (energy gives power / power gives energy / energy is power)
   - current, electricity

2. Formula (e.g. formula for an energy form / $E = mc^2$

3. Energy is needed for...
   - global, for all purpose)
   - living beings
   - technical appliance)
   - activities (physical)
   - light, heat
   - others

4. Energy is contained in ...
   - fuels (nuclear too)
   - things in motion, stretched, lifted
   - food
   - sun, wind
   - power plants

5. Energy conversion, energy transfer

6. Energy conservation

fig. 22: Categories for task 2: description for energy

Evaluation categories for part 2

The scheme presented in fig. 23 is used for tasks 5 and 6 as well with some slight modifications.

1) *One may miss the aspect of energy degradation (aspect 5) among the categories of fig. 22. In trial runs this aspect was very seldom mentioned. If it is mentioned it is to be found in a list of answers collected under the category "others".*

1. Explanations concerned with the geometry

- steepness of the path
- length of the path
- compensation of steepness and length
- symmetry / asymmetry

2. Used concepts for explanation

- motion, drive or other concept of everyday language
- force
- energy
- conservation of energy
- work

3. Other explanations

- there is no friction
- attraction of the earth (gravitation)

fig. 23: Categories for tasks 5 and 6 (ball moves without friction)

Fig. 24 contains the categories for task 7

1. Used concepts for explanation
(details see fig. 22)

2. Explanations for "car stops before A"

- weight is greater • friction is greater • more force necessary
- speed is less in the second trial

3. Explanations for "car stops at A"

- compensation: more friction but more drive too
  more friction but more energy too

4. Explanation for "car stops after B"

- weight is greater • drive is greater • energy is greater
- force is greater • acceleration is greater
- speed is greater • mass is greater
- energy (or drive) is greater and friction is not greater (or increase in friction is less)

fig. 24: Categories for task 7

Both schemes of categories point out my interest in the explanation given by the students. With regard to the aims of the studies the use of the word energy and the principle of energy conservation is contained. Furthermore some other categories shall reveal the notions of the students dealing with the presented problems.