The development of 1st year education students' ideas on energy, as a result of a specially constructed instruction

G. S. Ioannidis, D. M. Garyfallidou[(*)], D. G. Vavougios
The Science Laboratory, School of Education, University of Patras, 26500 Rion, Greece

G. S. Ioannidis, Associate Professor, Head of the Science Laboratory, University of Patras, gsioanni@upatras.gr
D. M. Garyfallidou[(*)], M.Sc., and Research Student University of Patras, d.m.garyfallidou@upatras.gr
D. G. Vavougios, Ph.D., Lecturing at University of Thessalia and at University of Patras, dvavoug@upatras.gr

Conference Theme: Learner representations and conceptual models in Science
Educational Level: Tertiary Education
Paper Classification: Empirical Investigation

Abstract: The present study focuses on the development of arts students' ideas on energy, as a result of them being subjected to an especially constructed tuition, given to them as an introduction. Some 175 Greek university students participated in this trial. Having established, from a previous study, that energy as a concept is not clearly understood by the students, and having attempted an informative guess as to the reasons of their misconceptions, a didactic attempt was made to clarify the confusion. The transformation of the students' ideas on various aspects of energy, its forms, its uses, its qualities, as well as the quantity essential to complete an everyday task, were all carefully monitored. Special emphasis was given to energy forms, renewable energy, as well as practical considerations relating to the use of energy and the everyday consequences of such use. Some interesting conclusions are drawn, pointing to possible changes needed to the teaching of this pivotal concept to the understanding of nature.

Keywords: students' ideas, energy concepts, science education, physics education, evaluation, pedagogical issues, university teaching, energy, teaching energy.

Περίληψη: Στην παρούσα εργασία παρουσιάζεται η εξέλιξη των ιδεών πρωτοετών φοιτητών παιδαγωγικού τμήματος, σε σχέση με έννοιες που σχετίζονται με την ενέργεια. Για τη μελέτη αυτή σχεδιάστηκε και χρησιμοποιήθηκε μία διδακτική παρέμβαση. Το δείγμα αποτελείτο από 175 Έλληνες φοιτητές. Έχοντας ήδη ερευνήσει τις παρανοήσεις των φοιτητών σε σχέση με την ενέργεια, επιχειρήθηκε μια πρώτη ερμηνεία των δεδομένων αυτών. Σχεδιάστηκε κατόπιν μία διδακτική παρέμβαση με στόχο την αποσαφήνιση των ιδεών αυτών. Ιδιαίτερη έμφαση δόθηκε στις μορφές ενέργειας, τις ανανεώσιμες μορφές ενέργειας, στο διαχωρισμό των πηγών και των μορφών ενέργειας, τη χρήση της ενέργειας και τις επιπτώσεις της στην καθημερινή ζωή. Η εξέλιξη των ιδεών των φοιτητών σε σχέση με όλα αυτά καταγράφηκε προσεκτικά. Μερικά ενδιαφέροντα συμπεράσματα εξάγονται, που υποδεικνύουν αναγκαίες αλλαγές στην διδασκαλία της ιδέας αυτής που αποτελεί κεντρικό σημείο αναφοράς στην κατανόηση της φύσης.

Introduction

Science and technology are omnipresent in everyday life and also play a very important part in today's culture. As a result of their pre-eminence, school curriculum should try to comply with these new data. Students should study science:

- To gain knowledge about the material world, simply because it is both interesting and profoundly important – and to feel the sense of excitement that scientific knowledge brings[1].
- Because science is an integral part of human culture and as it thrives on independent and creative thought, understanding science develops one's independent and creative thinking[2].
- Because the practice of science embodies norms and commitments, which are of wider value[3].
- Because education should, also, aim to attract a greater number of young pupils to study science, so as future scientists and engineers emerge from them[4, 5]
- Because the economic strength, the progress and the wealth of all modern societies is based on Science and Technology[6]
- Because needs to understand some science to manage the technological objects and processes they encounter in everyday life[7].
- Because the ever-growing importance of scientific issues in our daily lives demands a populace who has sufficient knowledge and understanding to follow science and scientific debates with interest, and to

[1] Bell D., et. al., *Beyond 2000: Science education for the future*, in Millar R. and Osborne J. (Eds.), *Beyond 2000: The report of a seminar series funded by the Nuffield Foundation*, ISBN 1 871984 78 5, (1998) p. 11.
[2] Verganelakis A., Who needs Physics, (in Greek), Democritus Nuclear Research centre, (1985) p. 2.
[3] Driver R. et al., Young people's images of Science, Open University Press 1996, p. 11.
[4] Solomon J., Teaching Science, Technology and Society, Open University Press (1993) p. 17.
[5] Bell D. et. al., *Beyond 2000: Science education for the future*, in Millar R. and Osborne J. (Eds.), *Beyond 2000: The report of a seminar series funded by the Nuffield Foundation*, ISBN 1 871984 78 5, (1998) p. 12.
[6] Solomon J., Teaching Science, Technology and Society, Open University Press (1993) p. 17.
[7] Driver R. et al., Young people's images of Science, Open University Press (1996) p. 11.

engage with the issues science and technology poses – both for themselves individually, and for our society as a whole[8]

For all these reasons, more emphasis and more time should be devoted to science and technology lessons at school and, furthermore, any tuition should follow **constructivist** theory and practice.

To this effect, in the present study the ideas (and misconceptions) of the students leaving high school and having taken arts as elective have been studied. The concept of energy is "fundamental" in Physics and therefore it could not be explained[9] using other (more fundamental) concepts. The energy concept, on the other hand, can be used to clarify other (derivative) concepts.

Energy is, nevertheless, essential in understanding the world. Every living organism (be that plant or animal) needs energy to sustain life. Furthermore, man needs some extra energy:

1. In agriculture, to produce fertilisers, to cultivate, to harvest, to pack and to preserve food. More energy is needed for some light industrial production as, for example the food preparation industry, or cloth making.
2. To power the machines that produce industrial objects.
3. To dig the earth, to extract mineral ores, to produce metals, shape them to useful objects, and to transport them.
4. Finally, energy is needed for all appliances and machines in daily use (transport, heating appliances, electrical apparatuses)

With the progress of time humans found their energy needs to be increasing for a variety of reasons:

1. Energy needs are increasing as a result of population rise.
2. Energy needs are growing as a result of the increased use of technology.
3. The "total energy use per head", is increasing (more or less) ***linearly*** as the "income per head" rises

The world total needs for energy are increasing as human population is increasing. As a result, total energy demand increases. On the other hand, the rise in the cost of energy has led to the design and construction of more efficient machinery. It has also led to a reconsideration of the production processes with the aim of reducing energy use. All these result in a less steep "energy use" versus "personal income" curve. Nevertheless, the above-mentioned function remains linear, through the ages. This fact reveals an underlying truth: the personal standard of living is directly related to energy use. Energy, therefore, is of primary concern in the economy as much as in everyday life.

As the concept of energy is both "fundamental" and essential to the understanding the world a lot of basic science education research has been conducted[10, 11, 12, 13, 14] during the past 2 decades. In addition to those, some other research has been conducted[15, 16, 17, 18] on developing lessons and teaching material about energy (in general) while others focused on a single energy form.

The conclusions from all previous research have already led to some changes in the school curriculum. Lately, the concept of energy is also included in some environmental education curricula. All in all, how well is the concept of energy been understood by high school leavers?

---

[8] Bell D. et. al., *Beyond 2000: Science education for the future*, in Millar R. and Osborne J. (Eds.), *Beyond 2000: The report of a seminar series funded by the Nuffield Foundation*, ISBN 1 871984 78 5, (1998) p. 5.

[9] Feynman R., in Feynman et al. *The Feynman lectures on Physics,* volume I, Addison-Wesley publishing company (1963) p. 4-2.

[10] Brook A. and Driver R., Aspects of secondary students' understanding of energy, full report, University of Leeds (1984) pp. 1-117.

[11] Driver R. and Millar R., Energy matters, Centre for Studies in Science and Mathematics Education, University of Leeds (1985) pp. 1-199.

[12] Driver R., Approaches to teaching Energy, Centre for studies in Science and Mathematics Education University of Leeds (1987) pp. 1-132.

[13] Solomon J., Getting to know about energy - in school and society, The Falmer press (1992) pp. 1-201.

[14] Duit R., and Haeussler P., Learning and teaching energy, in Fensman P., Gunstone R., & White R. (Eds.), *The content of science,* The Falmer press (1994) pp. 185-200.

[15] Duit R., Learning the energy concept in school-empirical results from The Philippines and West Germany, Phys. Educ. **19** (1984) pp. 59-64.

[16] Solomon J., Teaching the conservation of energy, Phys. Educ **20 (**1985) pp. 165-170.

[17] Brook A. and Driver R., The construction of meaning and conceptual change in classroom settings: Case studies on energy, Centre for Studies in Science and Mathematics Education, University of Leeds (1986) 319 pages including appendix.

[18] Kirkwood V. and Carr M., A valuable teaching approach: some insights from LISP (ENERGY), Phys. Educ. **24** (1989) pp. 332-334.

The research and the specially constructed tuition

Teaching the concept of energy is a complex issue and in doing so various hurdles have to be overcome by the teacher. It has been established, from previous studies (including one from our group), that energy (as a concept) is not clearly understood by the students. The mere fact that energy (as a concept) is encountered in many (if not all) the major physics chapters, leads to a fragmentation in the way the concept is discussed and taught. The many energy forms (each one appearing in different context and each one contained in a different chapter) exaggerates the problem. The various unscientific quotations in the mass media about "increased energy consumption" or the inevitable "energy crisis" liberally coupled with ecological concerns, all presented in a dogmatic and authoritative manner, only help to increase the confusion and to add to the reader's feelings of guilt. There are indeed ecological and economic aspects of energy use, but not the ones presented by the media. The nutritional aspects of food energy can also be (and sometimes are) taught in both biology and hygiene lessons. All these sources of information mentioned above, often misleading and almost always incomplete, add to the pupil's confusion.

Having done the aforementioned informative guess as to the origins of the pupils' misconceptions, an attempt was made to clarify the confusion through a specially designed lab activity based on the constructivist learning theory. According to ***constructivism*** much emphasis should be paid on students' ideas, as these represent the raw material that the students themselves are called-for to reconstruct. Teachers only play a supporting role in this process, and the support they offer (their teaching) is greatly improved when they have prior knowledge of their pupils' ideas.

According to Duit[15], there are five different aspects of the energy concept, serving as a framework to teaching energy. These are *(a) conceptualisation of energy, (b) energy transfer, (c) energy conversion, (d) energy conservation, and (f) energy degradation.* The lab activity was designed on the basis of the aforementioned points, taking as a starting point the results of the first questionnaire of our study, using the constructivist approach. The lab activity was:

1. Focused on teaching energy, by unifying the teaching of all forms of energy into a single teaching unit.
2. Centred on examples of energy usage and explaining the needs of such use.
3. Aiming to be complete and scientifically correct.
4. Based on many examples and selected pictorial material.
5. Explaining that not all forms of energy are equally useful (transmission, storage, and transformation issues).
6. Explaining the economics of energy production (be that large or small scale) as well as the intricate connections of energy usage, production and economic development.
7. Presenting the ecological dilemmas concerning energy usage and various commercially available methods of satisfying such demand.
8. Clarifying the misconceptions emanating from the mass media.

The research on the subject is still an ongoing effort, by members of our group. Therefore, the present paper focuses not so much on the details of the didactical intervention attempted, as to some first results referring to the transformation of the student's ideas on various aspects of the concept of energy and its usage. For this reason, no attempt will be made to compare the present (preliminary) outcome presented herein to the results obtained by other researchers using alternative teaching approaches or methodological tools.

Data

The present study focuses on the development of students' ideas on energy, as a result of them being subjected to an especially constructed tuition, given to them as an introduction. Some 175 Greek university students studying for an arts degree participated in this trial. Their ideas were examined: (1) ***Before*** they attend any science courses at the University and (2) a few ***months after*** they have attended specially constructed laboratory classes on energy. The time that elapsed between the laboratory classes and the second test was deemed essential so as to measure the remaining knowledge as opposed to whatever they memorised during class.

Various ideas of high school leavers were examined, a number of which are compared in the present study. These are the following:

- Renewable and non renewable energy forms.
- Renewable and non renewable energy sources.
- Nuclear power plants.
- Sun and the origin of its energy.
- Sun and its contribution to the energy chain.
- Energy for sustaining life of biological organisms.

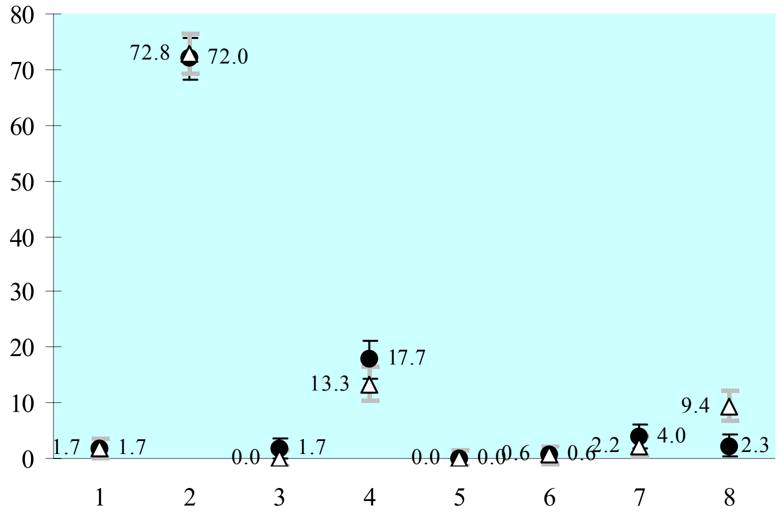
All relevant statistics were calculated using specially constructed software, interfaced with a popular computational and plotting package. The statistical variance was computed and the Bessel-corrected standard deviation was calculated for all data points presented. No experimental measurement can avoid systematic errors. In the present study special care was taken so that large systematics were avoided. The remaining systematic error was then evaluated, and was set at 1.5%, a figure considered to be fair and which is consistently comparable with all our statistical errors. This means that we believe our total error to be mainly statistics-dominated. The total error was then found by adding in quadrature the systematic with the statistical errors, these two being independent, by definition.

The data are mostly presented in double histograms, depicting the percentage of students holding a particular idea before and after the lab teaching. In the following histograms the data-points marked by a circle denote the pre-test whereas the data-points marked by a triangle denote the final test. The error bars on each point of the histogram represent one total standard deviation on either side of the point, as computed for this single point. The numerical various of the data are given on the histogram, staggered on either side of the points (for the pre-test circles they are on the right side, whereas on for the final-test triangles they are given on the left).

In ***some*** of the questions students were allowed to offer more than one answer. For the above reason, it is possible (for some of the questions presented) the sum of the percentages to add-up to something above 100.

Explain what you understand by the term “Renewable energy sources”

No observable difference exists in the data, below. It would appear that the overwhelming majority of the students understand the above question. The teaching of the meaning of renewable energy sources could be dropped altogether as superfluous from university curricula.

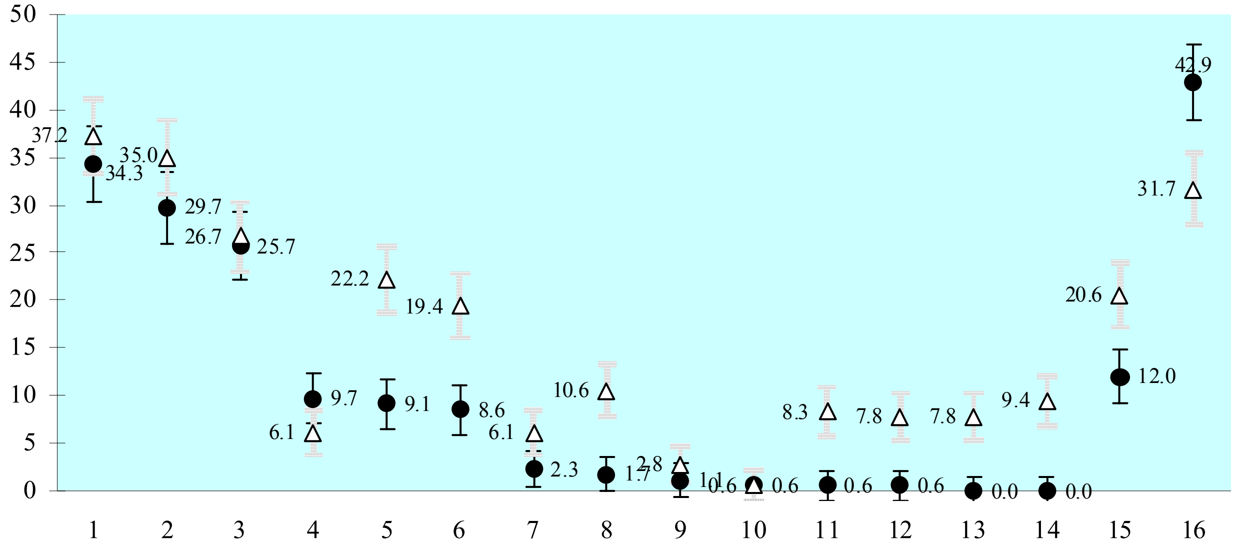


• circles stand for pre-test
∆ triangles stand for final test

1. Energy sources that neither pollute nor destroy the environment
2. Energy sources that never end
3. Answers 1 and 2 combined
4. Energy sources that exist in abundance on earth like mineral oil
5. Energy sources that do not emit radiation
6. Energy sources who do not destroy the ozone layer
7. Any other answer (please explain)
8. No answer given

Name as many renewable energy sources as you can

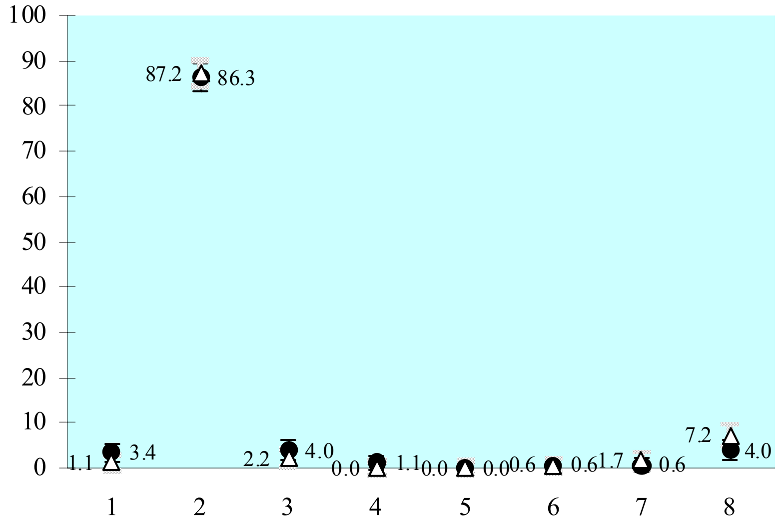
On the pre-test a 42.9% (± 3%) did not answer this question. This falls to 31.7% on the final test. A first observation is that there is still a wide spread confusion amongst the terms “energy sources” and “energy forms”. After we bypass this notable observation, we observe that there is a marked increase of the number of students who select “sun”, “wind” and “geothermy” as renewable energy sources. Nucleus, tides, sea waves and biomass were also (correctly) favoured as answers, whereas their contribution before the specially constructed tuition was negligible. Of these last, only the nucleus is in widespread use today, and therefore the small percentages appearing are understandable. More effort should, perhaps, be paid to explaining what a breeder reactor is, so as to improve the percentage of students recognising that nucleus is also a renewable source.



• circles stand for pre-test
△ triangles stand for final test

1. Sun
2. Wind
3. Water
4. Mineral oil
5. Solar energy
6. Wind energy
7. Hydroelectric
8. Geothermal
9. Thermal
10. Coal
11. Nuclear
12. Tides
13. Sea waves
14. Biomass
15. Various assorted answers
16. No answer given

Explain what you understand by the term "non-renewable energy sources"



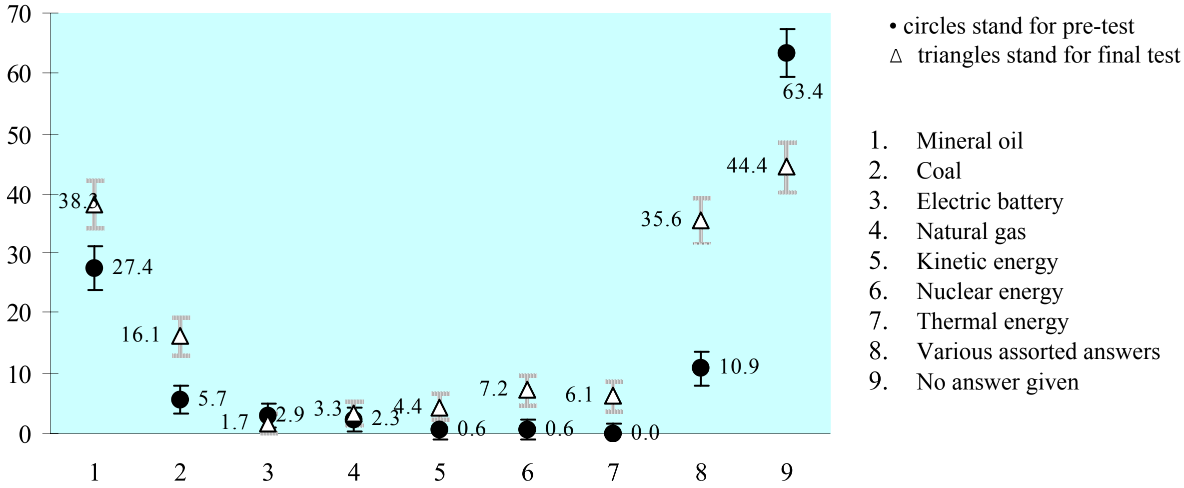
• circles stand for pre-test
△ triangles stand for final test

1. Energy sources that pollute or destroy the environment
2. Energy sources which are depleted and will eventually run out
3. Energy sources of unlimited quantity
4. Energy sources that do not emit radiation
5. Energy sources that emit radiation
6. Energy sources that destroy the ozone layer
7. Any other answer (please explain)
8. No answer given

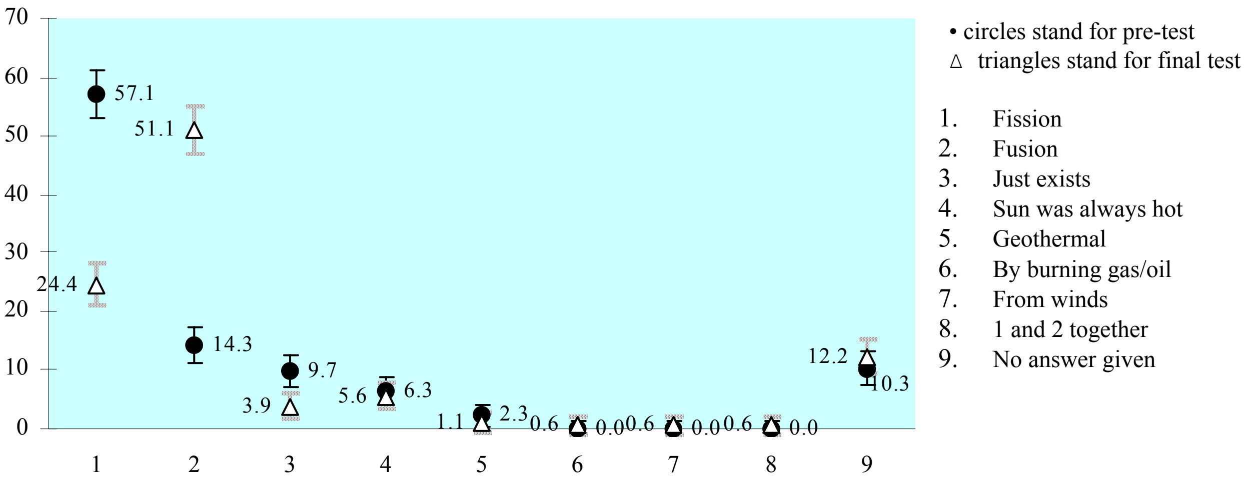
There is effectively no difference amongst the two sets of data. It would appear that the overwhelming majority of the students understands the above question. Not much attention should be paid to this during teaching.

Name as many non-renewable energy sources as you can

A most remarkable observation is that although coal (which in the form of lignite) is the main energy source in Greece (where the test was conducted), a pitiful 6% thought of it during pre-test, a figure that was improved in the final test but not to the extent that was envisaged. This problem was unforeseen and the tuition did not stress this point, as it should. The group given under "assorted answers" hides a wealth of information. It is felt that an investigation of a more detailed nature is needed to reveal the fine points regarding this.



The students' ideas on origin of sun radiation

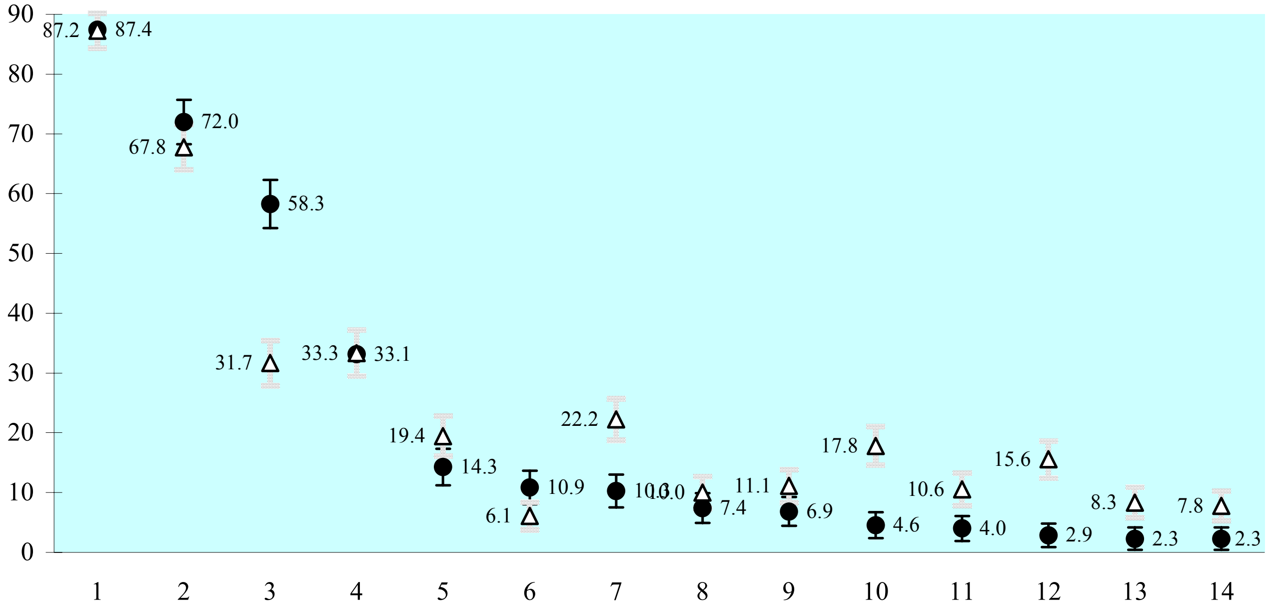


The majority of the students have already had a vague idea about the origin of sun radiation. They know that it was nuclear of some sort or another. After the special tuition, it seems that they have converted to fusion. It can also be seen that a 16% (9.7+6.3) respond "just exists" or "sun was always hot", which is the "dogmatic" approach. The small minority choosing "sun was always hot" seems unaffected and by that we can conclude that these are the stubborn sort.

Students' ideas on what is the sun responsible for

We observe that the majority of the students started their answer with a tautology: the sun is responsible for its own radiation. Their second choice "for the formation of life in earth" must be the result of biology and physics lessons. Their fourth choice "the geological formations and ground shaping" is peculiar. If we combine this to their 6th selection "earthquakes" and to the 9th "volcanoes" (which are not large percentages but which were totally unexpected), we end up in a serious misconception that should be examined further.

Concerning the 58.3% that selected "geothermal energy" on the pre-test, we now believe that it warrants special investigation in the future, as it may conceal a major misconception.

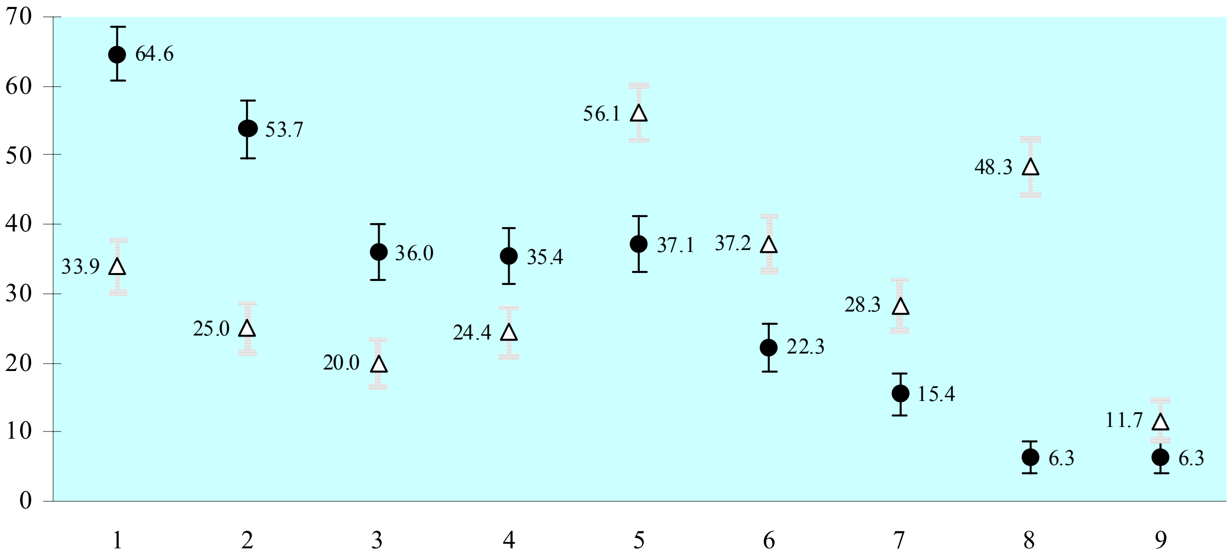


• circles stand for pre-test   △ triangles stand for final test

1. Solar energy
2. For the creation of life in earth
3. Geothermal energy
4. For the geological formations and ground shaping
5. Nuclear energy
6. Earthquakes
7. Biomass
8. Wind energy
9. Volcanoes
10. Tidal energy
11. Wave energy
12. Oil and coal formation
13. Hydroelectric energy
14. No answer given

It is also worth mentioning the small percentage of students that connects wind energy to sun radiation, although their majority gives it as an energy source. Mineral oil and coal are very much indirectly connected to sun radiation, and although the connection was explained, it is understandable that quite a lot of the students failed to make the connection.

The students' ideas on nuclear power plants



• circles stand for pre-test   △ triangles stand for final test

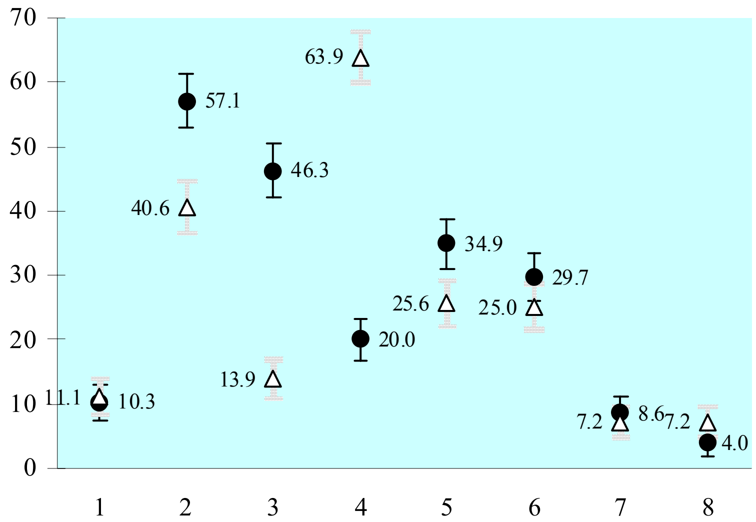
1. The nuclear power plants should only be built in uninhabited areas. A large area around them can neither be inhabited nor cultivated.
2. The water used in a nuclear reactor to rotate the turbines is radioactive and dangerous for man
3. A nuclear power plant radiates to the surrounding area and the atmosphere large quantities of radioactivity, which are harmful to humans.
4. A nuclear reactor is less friendly to the environment than a thermal power plant.
5. The safety measures are so high that any radiation leakage is very small. It could be argued that the inhabitants of an area rich in uranium minerals are subject to a higher radiation level than those who live near and work in a nuclear power plant.
6. A thermal power plant could emit to the environment a larger amount of radioactivity and radioactive waste than a nuclear power plant.

7. The water used in a nuclear reactor to rotate the turbines is not radioactive. It can even be used as drinking water.
8. The area around the nuclear power plant is not radioactive and can be cultivated or be inhabited.
9. No answer given

We observe that during the pre-test the majority of students has a "negative" attitude towards nuclear power plants. The (most substantial) majority of students gave mostly contradictory and not self-consistent answers. From this it can be deduced that most students had a vague idea, if not complete ignorance of the subject. This was expected: The subject is not covered adequately by the school curriculum. Even worse, whatever pseudo-scientific articles in the mass media offer as knowledge, is inevitably wrong. The ensuing "in depth" analysis offered about the social and economic issues involved is totally devoid of any depth, but it works simply as propaganda, increasing the confusion. With the help of the tuition offered, this situation is improved to a remarkable extent, as the data reveal. The improvement is most obvious in the 5th and the 8th questions. The reason should be the demonstration of several relevant (safety and environmental) pictures in the lesson.

The students' ideas on how does man gains energy

It is clear from the pre-test data that students connect energy with food. An obvious explanation is the number of advertisements claiming that certain products give to our organism the needed energy. By comparing the 2 sets of data we observe that students, to a remarkable degree, have clarified after the tuition the process (burning) through which man gains energy. Their answers were a lot more vague or imprecise, beforehand. A notable observation is the number of students who thought that drinking water or breathing produces energy.



• circles stand for pre-test
Δ triangles stand for final test

1. When he sleeps
2. From his food
3. Through the digestion process
4. By burning down his food
5. When he drinks water
6. When he breaths
7. When he moves
8. No answer given

Didactical observations and conclusions

As already mentioned in the section outlining "the research and the specially constructed tuition", the research on the subject, by members of our group, is still continuing. Indeed, as this represent our first attempt to re-order students' ideas on energy, we do not consider our teaching to be perfected. Some interesting conclusions can be derived form the present data, nevertheless. These would come from three sources: (a) From the analysis of the pre-test alone, as this represents the outcome of years of traditional teaching at school. (b) From results derived from a comparison between the two tests, in order to establish that some progress (in comparison to traditional teaching) is indeed possible, using the teaching principles presented. (c) From didactical observations made during the teaching effort.

Any direct comparison with the results obtained by other researchers should be deferred for a later stage, when our research effort reaches a more conclusive stage. It could be argued, however, that the present post-test results, albeit not necessarily perfected, show a direct benefit in comparison to the pre-test results, corresponding to knowledge obtained after years of traditional teaching effort.

(a) A large number of secondary school leavers appear to have serious misconceptions on issues relating to the energy concept. The majority of students use the terms "energy forms", and "energy sources" without any distinction. A large percentage of them did not answer the open type questions of the pre-test, while they gave a try to the multiple-choice questions. It is plainly obvious that (at least as regards the energy concept) the present educational system has ***failed*** to provide suitable and adequate science teaching. The reasons for the serious misconceptions observed, ***might*** be searched amongst one or more of the following:

- Issues relating to energy are **inadequately** covered by the school curriculum.
- The school curriculum appears ***fragmented*** on matters relating to energy.
- The exposure to misguided and shallow ***pseudo-scientific articles*** in the mass media, dealing with energy issues.

(b) Pupils seem to **respond quite well** to the specialised teaching focused on energy, in which the concept is presented in a unified and complete manner. Trying to give definitions does not seem to be effective. Giving

examples is effective. If a conceptual shift needs to be achieved, pictorial, video, or hands-on evidence is most effective. When teaching energy-related concepts, an overall reference on economic, industrial and practical issues concerning energy appears to be effective.
(c) It was realised during the tuition that students did not appreciate the way common power plants (geothermal, nuclear, thermal, and hydroelectric) operate. They have also never heard that the hot water, after passing from the steam turbine of a power plant, could be used for heating a district. This is probably because (1) they did not understand the way thermal power plants work and (2) because this is never done in Greece, neither does it appear in any environmental curriculum or article. It was easier for them to accept that a water dam can be used both for a hydroelectric power plant and also for water supply. In fact, they thought of such a combined use themselves: Students in Greece are well aware of water shortages. They also found it most difficult to believe that a very efficient way to store large quantities of energy is to pump water up to a mountain-lake.
It appears that more research on this subject is necessary. We also believe that ultimately, more school time and effort should be devoted to the explanation of the various energy forms and energy transformations. The teaching of energy should start at a very early stage, at school. The sooner we can get in with using the idea of energy, even if only half understood, the sooner it will begin get established[19]. Finally, the teaching of the subject should be unified into a single unit.

[19] Holman J., Teaching about energy - the chemical perspective, in Driver R. and Millar R. (Eds.) *Energy matters,* Centre for Studies in Science and Mathematics Education, University of Leeds ISBN 0 904421 14 7, (1986) p. 48.