AC 2010-77: INTRODUCING ENERGY CONCEPTS INTO UNDERGRADUATE COURSES

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Introducing energy concepts into undergraduate courses

Students are used to manipulating energy-related concepts from media and everyday life. However, many general education students have never had a physics course and their understanding of energy, its production, use, importance, or impact in their daily life is very limited. We report on innovative efforts to facilitate the understanding of energy-related concepts in a General Education Physics course. We proceed with an initial evaluation of students' perception of energy concepts, which actually confirms the need for a more thorough understanding of energy concepts and of their importance. Throughout the course, energy concepts are gradually better defined and used for analysis of everyday life activities. Starting with mechanical energy, heat, electrical energy, Faraday induction law and energy conversion, photonic energy, and nuclear energy, physics offers a wide range for defining energy principles and demonstrating their applications and significance. Home projects meant to develop and clarify the use of energy are also assigned. An evaluation of the students' perception of the energy concepts is finally performed in a separate survey. Questions about energy conservation issues and the factors influencing them are also addressed, along with raising awareness of what students can do to help with energy conservation. The conclusions of our innovative development of the course and its results are detailed. Living in a technologically advanced world places high demands on educated workforce. We are hopeful that the procedures and positive conclusions of our study can be meaningful to other energy educators from other disciplines.

I. Introduction

The entire modern life is based on the consumption of energy essentially for all the human activities. Understanding the continuous increasing thirst for energy, production, use, and storage appears difficult in a developed society where many things available are taken for granted. Many scientific discoveries within the last 20 years have contributed to the development of third world countries become more competitive [1] and their development contributes to an even more acute need for energy. Studies indicate that US high school graduates tend to be less prepared for college studies in STEM areas than many other Western or Asian countries [2]. Science and engineering skills are essential for maintaining the United States' competitiveness in the increasingly knowledge-based global economy [3]. However, students often lack those skills [1] and are unaware and unable to assemble the impact of common activities around in a larger picture and have appropriate reactions to them. Physics is at the core of understanding energy concepts which are often difficult [4] simply because students may have never had the chance to take a Physics course and comprehend how energy principles are applied and make links to the real world. General class survey related to energy issues revealed such difficulties in our case. Hence, students have often may have very limited room for making any educated decisions relative to the energy concepts and policies in their daily life. Energy generation is fairly well present in our university environment as a fossil-fuel power plant is almost embedded in the university space (Fig. 1 a); moreover, one of the cooling towers (Fig. 1 a), belonging to one of the three nuclear power plant in the vicinity, is also part of the daily view students can have from certain parts of the campus. In such an energy rich environment and with the previous ideas as a starting point, we considered developing an introductory Physics course to a general student audience rich in energy concepts [5], more linked to the real world than we would have taught it otherwise. The course taught in a more engaged manner was meant to alleviate student understanding and usage of energy concepts. This paper describes our efforts in this direction along with an evaluation of the course outcome. The course was taught twice in a slightly different fashion. The comparison of the outcomes is further discussed.

(a) Campus view (b) Nuclear plant cooling tower view

Fig. 1: Power plants around the campus

II. An initial assessment of student opinion on energy concepts

Physics is indeed the field where most of the topics can be related to energy [6]. Whether we are talking about mechanical motion (at macro or micro level – molecular, atomic or subatomic), gravitational, electric, magnetic, or nuclear fields, there is always an energy associated to them. It is only up to the instructor how much develops on the application of energy principles and links them to the daily life examples. In our approach, we aimed at including many examples of “energetic” systems, energy conversion, and basic law of total energy conservation.

Newtons’s laws are the most basic for the mechanical description of system at rest or in motion at speeds significantly lower than the speed of light (this essentially includes all common environments). The moment we come to the point to define the mechanical work and mechanical energy, a survey was passed to the students in order to assess their initial understanding of energy topics. Here are some sample student answers:

Question: What is energy?

Answers: no idea, a force; ability to do work; the ability to work; no idea; is the movement or possible movement of an object; is the force that makes things move; the potential to do work; energy is everywhere and is required to move, live, produce heat, sound, … $E=mc^2$; energy is never lost but transferred; ability to effect change; is certain amount of force in objects; used to grow life and sustain it;

it is something produced by moving objects or potential movement; the concept of motion or a physical feature being transported to another object; something that is able to produce movement/heat; the measure of something's capacity to do work; it can be stored in many forms, and it is neither created nor destroyed, only converted from one form to another;

Question: Why is energy important?

Answers: we needed on a day to day basis; computers, TV videogames; energy makes things work; without energy nothing would happen; we need it to stay alive; it is required in all aspects of life; because is used to do work; makes things work; because a lot of things depend on it; because it is an everyday phenomenon; something that can cause motion; we need it for everything to live; energy helps things grow; it is everywhere; we need it; without it nothing would exist; we need it to survive; we need it to function as a society; it is the essence of everything; this is the fuel to move things; energy is used everyday – getting to school, turning on lights…; need it or we would all be still; we always need it to get things done;

Question: What is conservation of energy?

Answers: stored energy; energy is transferred not made/lost; storing energy to be used later; for every action there is a reaction; energy cannot be destroyed - it changes from one form to another; transfer of energy from one thing to another; when you have kinetic energy equals potential energy; conserving energy; no idea; allow things to have motion; without it we have no power; it gets us through the day; energy cannot be created/destroyed; how energy can go from one state to another and be accounted for; energy never being lost – it just goes from place to another; energy that is stored; trying to save energy and not to use so much; energy that is saved; lights use, heat use; it sticks around; it is neither lost nor created; energy cannot be created nor destroyed – it can only change forms; conserve not to overuse our capabilities; when the amount of energy before and after is the same; the study and regulation of energy uses; is one of Newton's laws that energy is neither created or lost in a system, only converted; the idea that energy isn't created or destroyed – just converted to different types.

Question: What is energy conservation?

Answers: no idea; using energy in a responsible manner; turning the lights off when you leave the room; not wasting energy; the idea that we can have energy; is when final energy and initial energy are equal; energy is not lost or gained; using less energy than one would normally would; saving energy or doing things to try not to use so much energy; storing energy for later uses; when we try to save energy; regulating use; the ability to keep an object energy without losing any; looking for new ways to save/renew energy; not wasting useful/"scarce"/expensive forms of energy.

Question: What energy conservation issues are important in our lives?

Answers: no idea; oil; we are using a lot of oil; conservation of petroleum based fuels; global worming; using less energy that was produced using methods that release carbon into the atmosphere; oil, gas conservation, electric conservation; fossil fuels; kinetic energy and cars; the overuse of resources such as electricity, food, and raw materials is of concern – only through conservation can we maintain the resources to survive; future generations can be affected; oil, electric; the ability to never run out of energy is important in our society; windmill industries, biofuels, -looking for new ways to use energy; use less gas and save money; most current forms of energy production pollute the environment in some way so we want to conserve as much as possible by being efficient.

It is apparent that students have heard about energy topics and in general have an opinion about them. However, the content of the topic is rather confusing. Correct and false ideas often go together. There is a general feeling for what energy is and why it is important. Conservation of energy and energy conservation seem to be even more confusing although there are good student responses among them. A few energy conservation topics are known to students but it seems they are very rarely relating those issues to what they can do to the process. This fuzziness was gradually diminished as the course progressed.

III. Energy concepts in an introductory Physics curriculum

The topics of a general introductory Physics course usually include: Classical mechanics (Newton's laws), Energy and Oscillations, Electrostatics, Basic electrical circuits, Magnetism, Waves and light, Nuclear energy. The universal nature of energy offers an ideal centerpiece for restructuring of an introductory Physics course [6].

Classical mechanics offers the chance to define kinetic (translational and rotational) and potential energy (particularly in gravitational field and elastic forces) of systems. Application of energy principles to equilibrium of objects or systems leads to the classification of equilibria into stable, unstable corresponding to maximum or minimum potential energy of the system. Examples are everywhere around us if one is aware of the concepts related to equilibrium. A particular exposure to energy concepts was thought to be implemented through the homework and home experiments. Accordingly one homework asked students to find such examples.

Electric field and electricity topics are less intuitive than mechanical phenomena as one does not directly see the electric field and charges. Energy associated to the electric field and follow of charges was defined and consequences and energy conversion phenomena (such as: thermal effect of a current in an incandescent bulb, repelling of the plates of an electrometer due to the accumulation of charge, or air breakdown on a Van der Graaff machine).

Magnetic field and interaction is an important and interesting topic. Magnetic field carries energy that can be converted into mechanical energy easily to notice. For instance the magnetic interaction of two magnets leads to mechanical motion (essentially conversion of the magnetic field energy into mechanical energy).

The close inter-link of the electric field and the magnetic field are best explained by the Maxwell equations which predict the propagation of electromagnetic waves in vacuum at the speed of light. Bothe electric and magnetic field carry energy which can also be observed as photon energy which for instance can be observed by means of energy conversion to heat, motion, electricity or interaction with human tissues (higher frequency electromagnetic waves carry more energy and create more damage such as X-rays and gamma-rays). Other waves (mechanical) also carry energy. The ocean and lake waves are impressive; their energy activity and power consequences can be and is admired by the student right on campus which leans along the lake.

The famous Einstein equation $E=mc^2$ can make us think of energy associated with matter around us. The nuclear plants generating energy according to this relation are a constant presence for the student on campus as they see over the lake one of the cooling towers of the three nuclear plants in the neighborhood.

Although the course was not a specific course on energy but more than usual energy topics were stressed throughout the course. The above stand as examples for what energy topics and connections to real life the Physics curriculum offers which can make students have an educated opinion relative to energy issues embedded in their lives.

IV. Invited energy talks

Two invited energy talks (two specialists in the field) were organized for the first Physics course and one for the subsequent course. The first energy lecture (delivered close to the mid-semester) tried to make aware students about the energy problems in the world and what students can do about them. It made a link to globalization, and energy impact on society. The second lecture (different lecturer, delivered about the end of the course) was on global energy issues and alternative energy. The talk was more specific and focused on the long term impact on society of energy policies, use and generation. An essay paper 2-3 pages long, based on the topics of the lecture was requested each time and graded at the weight of a quiz. The essay was supposed to wrap up the ideas discussed in class and develop more on a energy research topic of choice.

Many students were shocked by the first lecture that confronted them with problems, policies and consequences to the daily life that they were not aware of. Many of them did not know that United States relies heavily on energy imported from countries which aren't USA allies. While many of the students were greatly pleased with having insides in direction fairly different than their own thinking, some were challenged almost too much. For instance there were many comments of this type: "Dr. X was a great person to come to class. He gave a great talk on energy and on economic situation of our country. I really enjoyed how he used the class how he used the class to perform discussions and make people think", "Professor's X speech really struck me", "he related the principles we have learned in Physics and real life examples of these principles in action", "the information he gave to us I found very useful and very thought provoking; I appreciated having a speaker come into the class and I believe that it was good to introduce real world applications into the scientific knowledge we have gained" or "during today's class we had a brilliant guest speaker to give a lecture about energy issues and other problems facing our economy." At the same time, we had comments of the kind: "the speaker talked about many different topics and none that pertain to Physics", "the lecture was more about discussing problems that our world currently having…I believe that our speaker is a smart man and is probably a good teacher for whatever subject he teaches but I did not enjoy his presentation".

The second lecturer focused more on alternative energy sources including solar, wind, and nuclear energy. More specific and updated information was provided during this lecture. The student response was more balanced this time maybe due to the fact that they had already been exposed to some of the topics in the previous lecture. Here are some comments about the lecture:

"I found the presentation to be very informative… I feel I did learned a lot that can be used on an everyday basis", "students need to be exposed as a young age about energy; that is just how it need to be", “in my lifetime I have seen gas prices go up more than $2 (200%);when something that is so valuable to the way we run our lives can fluctuate to such an extreme there is reason to be worried…students should be learning about how the world works and how to make the world a better place for all of us”, “I found the lecture on Friday to be particularly interesting… I have done a great deal of research into alternative energies. I think this lecture conveyed a great deal of information that was both interesting and informative”, “the more I learn about energy in the lecture the more I am concerned about how long the energy will be left and how will people do and live later when the energy source are exhausted”, “he allowed us to see both pros and cons of ways of helping save energy, when most of the time we are just given one side”, “having more information on the earth and our environment is key to becoming a more responsible society; I am glad to have heard Dr. Y and I hope to hear him again”, “the part I found most interesting was the site he mentioned [7]. This site discusses how mountains are being blown up and torn down in order to mine coal and they just smoothed over as they have never existed. On this site I was able to enter my zip code to see if I have any connection to the mountain destruction and to my surprise I had. The company that my family and I receive electricity from receives coal from other companies that destroy mountains” , “in the future I am going to be much more energy conscious and try not to be wasteful”, “alternative energy is not an option but a must”, “coming to Physics class to hear Dr. Y’s presentation on energy was a great experience”, “Dr. Y lecture was an eye opener looking at how much energy human beings are wasting”, “he brought up many facts about the different energies that I have always wandered”, and “I believe that change must begin with each individual; in fact I have done and have plans to do many things to reduce my overall energy consumption and demonstrate my commitment to sustainability”.

It appears that the second lecture although overlapping in certain general aspects but mostly complimentary to the previous one, was very well received by the students. Students assimilated the structured information in a different way. Becoming more conscious of the global needs and problems helped them be more responsible persons in their daily life. The courses were taught slightly different so that there were two invited energy lectures first time and only one second time.

In addition to the energy topics embedded in the Physics course an optional energy-related home project was proposed for a few bonus marks as projects in the curriculum motivates student learning and facilitates understanding of class material [8]. There were eight project presentations for the first energy targeted course and five project presentations in front of the class for the second one.

A visit to one of the nuclear plants was intended but due to security issues the clearance time was too long to make the visit feasible. We might have another attempt next time the course is taught along with the initiative of inviting a lecturer for the plant during the class time.

V. Student perception on energy topics

An exit energy survey was run at the end of the course (Table 1). The scope was to evaluate the subjective perception of the students relative to their understanding of energy-related topics rather than using comprehensive tests [9] as physics laws were I fact the real objective of the course. A comparison between their pre-course perception and post-course perception was intended (questions 1 and 2). Also a relative self-assessment of their progress in this direction was addressed by question 3.

Table 1. Exit survey questions

Q 1: On a scale of 1 to 10 how important did you think energy conservation was before taking this course?
Q 2: On a scale of 1 to 10 how important do you think energy conservation is now?
Q3: On a scale of 1 to 10 do you think your understanding of energy concepts has improved?

The distribution of the student score assigned to their pre-course understanding of energy topics is given in Fig. 2. Set 1 data corresponds to the first time teaching the course in the adapted format and set 2 is associated with the second class teaching. Similarly, Fig. 3 shows student score distribution relative to their post-course perceptions. The vertical axis stands for frequency or how many students have assigned a particular score within a given score range (horizontal axis).

Table 2. Average scores for the two data sets

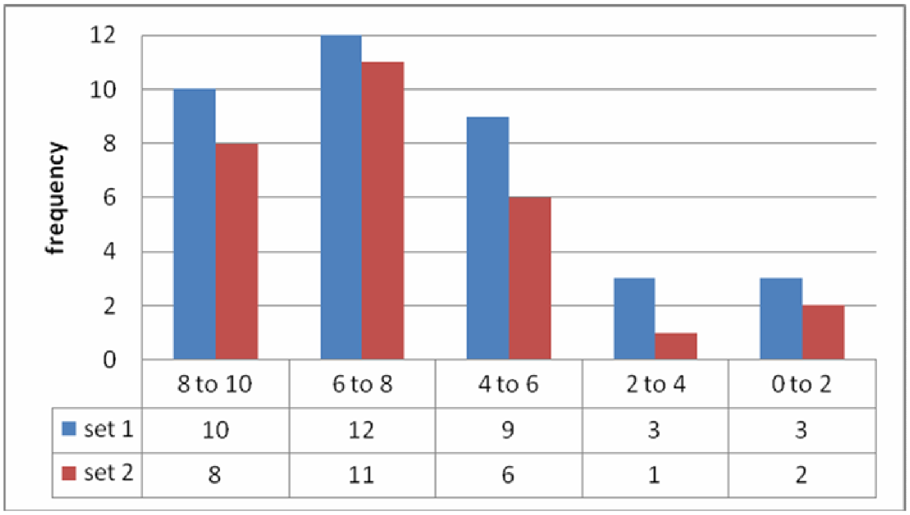
	pre-course (X_0)	post-course (X_F)	perceived improvement score (Y)	Ratio (R)	aggregate improvement score (AIS)
set 1	6.85	8.64	6.89	1.42	42.56
set 2	7.29	8.93	6.41	1.49	39.11

Table 2 shows the average values of pre-course and post-course student scores (columns 2 and 3), average perceived improvement in understanding importance of energy conservation topics (column 4), and average ratio between the post (X_F) and pre-course (X_0) scores for each student. The ratio was thought as a measure of student progress in assessing the importance of energy conservation issues. I addition, student responses to Q3 give their own assessment to progress in understanding energy concepts. An additional aggregate improvement score (AIS) was considered necessary in order to evaluate the overall student progress. AIS was defined as:

$$AIS=[100*(X_F-X_0)/X_F+10*Y]/2 \quad (1)$$

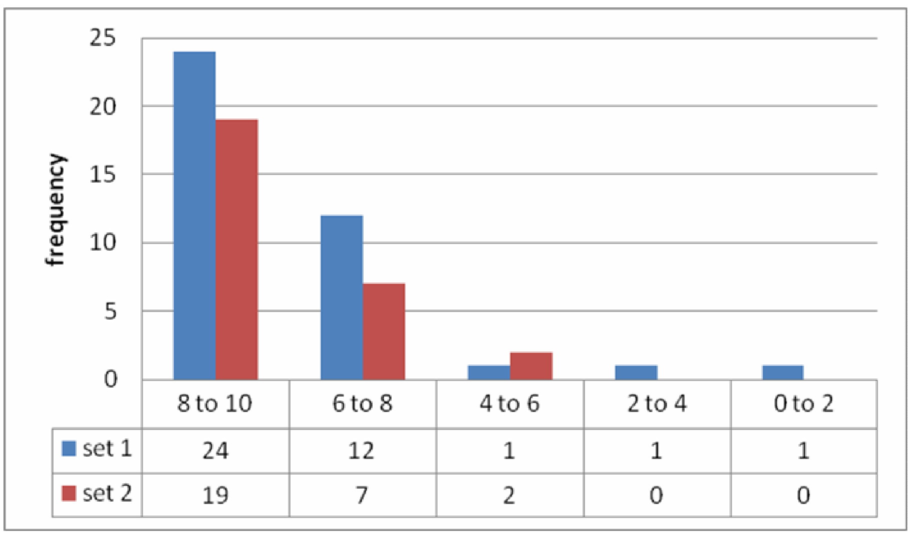
Where X_F is post-course score, X_0 is pre-course score, and Y is the improvement score (question 3). The AIS can range from potentially from 0 ($X_F = 0$; $X_0 = 0$; Y= 0 – pre-course no understanding at all of energy conservation and no progress at all during the course in understanding energy concepts) to 100 ($X_F = 10$; $X_0 = 0$; Y=10 – pre-course no understanding at all of energy conservation and maximum progress during the course in understanding energy concepts).

It is noticeable from Table 2 that X_{0set2} is slightly higher than X_{0set1} which points to the fact that initial perceived understanding in group 2 of energy conservation importance was better than for the first group. Also, X_{Fset2} is slightly higher than X_{Fset1}. However, the average improvement ratio R, is only slightly larger for set 2 than it is for set 1 indicating that the change in the perceived student understanding of energy conservation concepts is essentially the same for the two groups.



	8 to 10	6 to 8	4 to 6	2 to 4	0 to 2
set 1	10	12	9	3	3
set 2	8	11	6	1	2

Figure 2. Initial perception of energy issues in the student response per score range.



	8 to 10	6 to 8	4 to 6	2 to 4	0 to 2
set 1	24	12	1	1	1
set 2	19	7	2	0	0

Figure 3. Perception of energy issues in the student response at the end of the course.

The perceived improvement score Y is larger for set 1 than for set 2. This may correspond to the fact that the first group started with a lower background in energy concepts and achieved about the same level as for group 2 (that means more perceive progress indicated by the $Y_{set1} > Y_{set2}$). This conclusion is also validated by the $AIS_1 > AIS_2$ in Table 2 pointing to more overall progress in group 1.

Fig 2. Shows that the distribution of responses for Q1 follows essentially the same pattern for each data set. Set 2 corresponds to a slightly smaller class and a smaller number of responses, hence the slight difference in the frequency of responses per score range.

Fig 3 shows the distribution of scores corresponding to Q2 (Table 1). The pattern is fairly similar for the two data sets and reflects student confidence of having achived better understanding of energy conservation concepts.

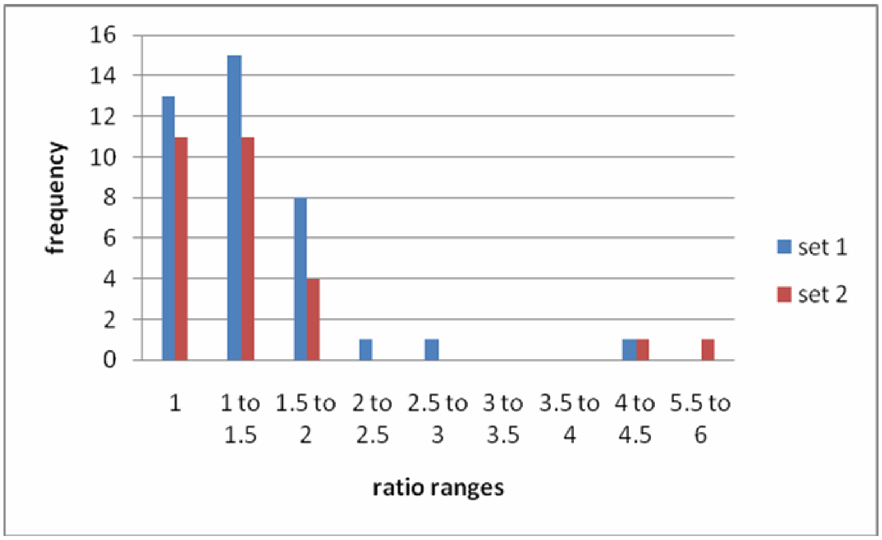


Figure 4. Distribution of student perceived improvement ratio R (post / pre course rating of energy conservation importance)

Fig. 4 shows the R distributions per ratio ranges with similar patterns for the two data sets. The figure shows that one third of the students for set 1 and slightly more for set 2 have not changed their ratings for pre and post course understanding of energy conservation concepts (R=1). That is partly due to the fact that maximum scores for X_0 (more than one third for set 1 and almost one half for set 2 out of the student with R=1) and no further improvement was possible. Those students had the highest awareness of the importance of the energy conservation issues. At the same time,most of the students have actually increased their post course rating substantially (some more than 500% - R>5).

Score distributions related to Q3 is shown in Fig 5. Again, the patterns for the two data sets are fairly similar except for the scores from 8 to 10 where relatively more student scores from set 1 belong to this range than for set 2. The score distribution shows that most of the students feel that they have substantially improved their understanding of energy concepts.

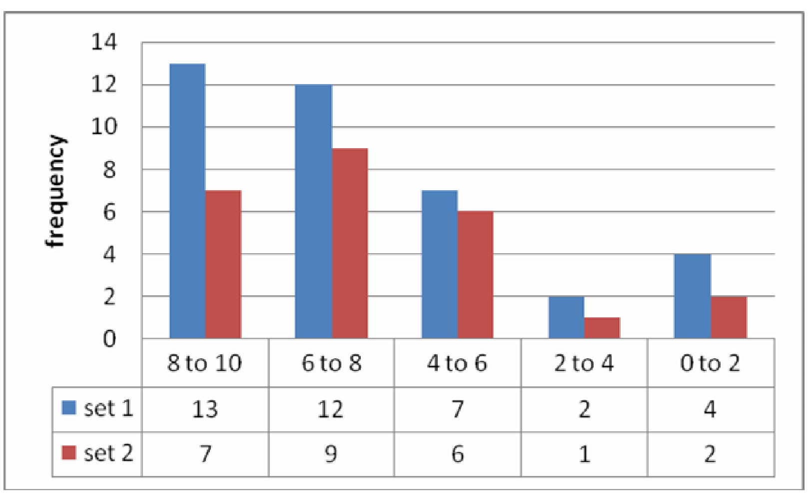


Figure 5. Distribution of scores for Q3.

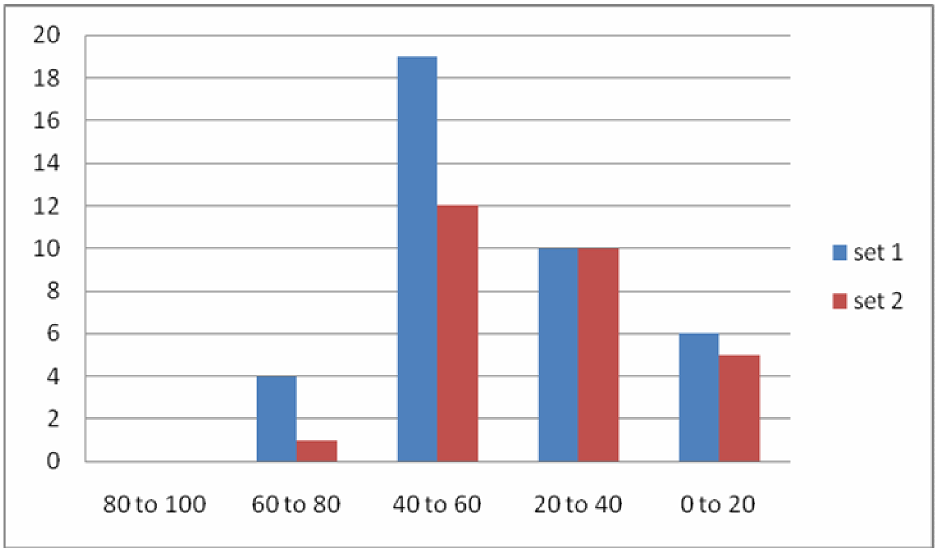


Figure 6. Distribution of student aggregated perception of improvement in understanding energy issues

The overall student improvement scores (AIS) are shown in Fig.6. Scores in the range of 80 to 100 are less likely as this would assume no knowledge of any energy concepts and the highest possible improvement during the course time. The patterns for the two sets are similar. Nevertheless, relative more score gains are recorded within 40 to 80 range for set 1 as opposed to set 2. This is in agreement that student group related to set 1 scores might have started at a lower knowledge level and their improvement was relatively larger than for group 2.

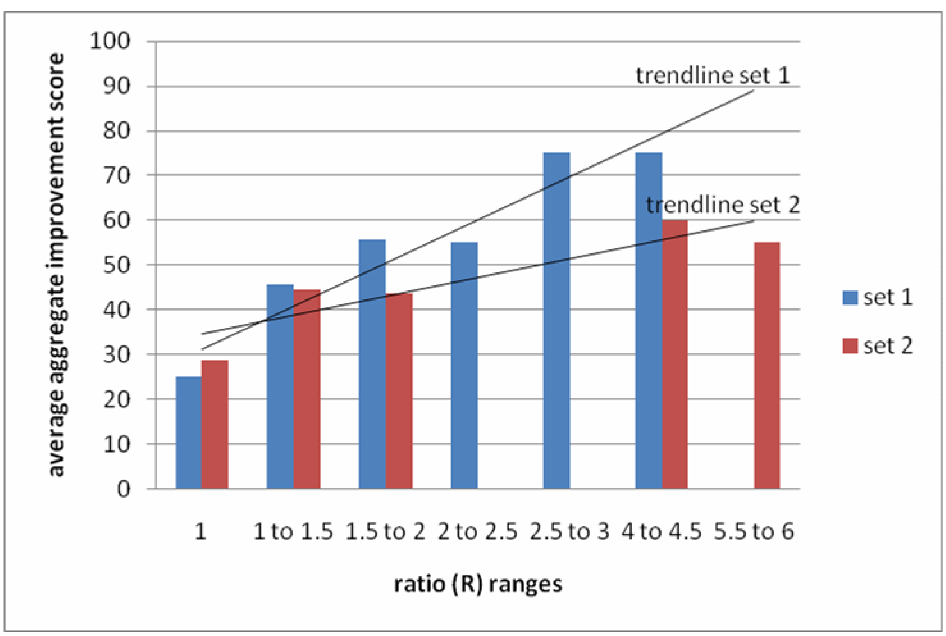
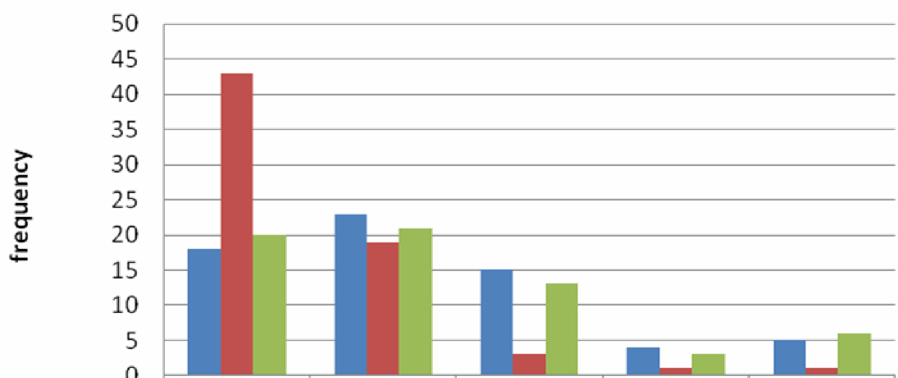


Figure 7. Average aggregate perceived improvement score per ratio range.

The relative improvement of student understanding was measured by R. For each R ranges shown in Fig.6 an average of the AIS was calculated and shown in the same figure. A clear trend in the overall improvement can be noticed, better revealed by the trendlines related to each data set in Fig. 7. According to the chart the larger the R the larger the AIS can be expected. That means the more students felt they had understood the importance of energy conservation issues the more they have also evealuated their overall understanding in understanding energy concepts in general. The trendline associated to set 1 is steeper than for set 2. That corresponds to a more perceived improvement in group 1 relative to group 2 possibly due to a lower starting point, the fact that two energy lectures were delivered to group 1 as opposed to one for group 2, and possibly to other random factors.



	8 to 10	6 to 8	4 to 6	2 to 4	0 to 2
Q1 scores	18	23	15	4	5
Q2 scores	43	19	3	1	1
Q3 scores	20	21	13	3	6

Figure 8. Distribution of student average aggregated perception of improvement in understanding energy issues per ratio range.

According to our analysis the results obtained for the two data sets follow similar patterns with some peculiarities. A final comparison of the aggregated data sets is shown in Fig. 8. A clear shift towards higher scores is noticed for the post-course responses to Q2 indicating a clear student perceived improvement. From the graph it appears that most of the improvement has happened to students with Q2 scores lower than 6 and it brought them to 8 to 10 range (Q3 responses). The student assessed gain distribution (responses to Q3) is also apparent as no gain in their understanding corresponds to a zero score.

VI. Conclusions

Many general education students have low understanding of energy concepts and their impact in their lives. In order to improve student perception of such issues, an Introductory Physics course was design to target more efficiently understanding energy and relation to real life topics. Our efforts were directed to the enhancement of the course with real life examples of energy principles, including homework, home projects, and invited energy lectures. From the student responses it follows that students were mostly welcoming the addition more intensive energy topics. Their progress was assessed using their feedback which reveals the following salient features:

- the response score pattern distributions are fairly similar for the two groups
- group 1 appears to have had a lower initial inside into energy-related concepts
- group 1 and group 2 appear to end up at about the same knowledge level
- the ratio R (Q2 score/ Q1 score) was confirmed as an indicator for the overall progress in understanding energy concepts
- a clear improvement in the student progress towards understanding energy concepts was proven from the analysis
- most of the students that had improved their understanding had Q2 scores lower than 6 and they plunged into 8 to 10 score range (Q3 responses).
- a very small nuber of students did not appear to had made any progress; most of those are the ones who had already been highly knowladgeable from the beginning of the course.

It appears that students perceived the course as a definite improvement to their awareness, understanding and likely to influence their future to make educated decisions. The course may likely be improved in the future by inserting two energy lectures rather than one, organizing a field trip to one of the energy plant in the region and perhaps helping more students to engage into energy-related home projects. We hope that our positive teaching experience can help other educators as well.

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