WHAT DO ENGINEERING STUDENTS UNDERSTAND ON THE FIRST PRINCIPLE OF ENERGY IN MECHANICS AT INTRODUCTORY PHYSICS COURSES?

José Gutierrez¹, Kristina Zuza² and Jenaro Guisasola²  
¹IMH Dual Ingenieering School – UPV/EHU (Spain)  
²Polytechnic College Donostia-San Sebastian- UPV/EHU (Spain)

Abstract  
This study will focus on the description of undergraduate students’ understanding of several physical concepts. Thereby, teachers could base their decisions about the interventions on the data in order to assist student learning. The data also show ways of improving teaching sequence designs as well as measurements of how developed the understanding is. This study describes some outcomes from the assessment of students' levels of understanding of some key concepts and principles in the area of Mechanics, specifically the first principle of energy.

Keywords: physics education research at university, energy first principle, students learning.

1 INTRODUCTION

Recently, the Report to the European Commission on Improving the Quality of Teaching and Learning in Europe’s Higher Education Institutions highlights the importance of introducing science as a creative process that draws up theories and concepts to achieve solutions to problems related to Science and Society. The purposes of European undergraduate education in science and engineering includes providing all students with the foundational knowledge and skills required to be successful in careers such as science and engineering. Science and engineering students must be able to solve problems, skilled in quantitative reasoning and cross-disciplinary collaboration, and cognizant of relationships between science and society. This study will focus consequently on the description of undergraduate students’ understanding so that teachers can base the decisions about their interventions to assist student learning. The data also indicates ways of improving teaching sequence designs so as to measure the development of understanding. This study describes some outcomes from the research of students' levels of understanding of some key concepts and principles in the context of first principle of energy.

The teaching and learning of the concepts of work, energy and the relationships between them, are particularly complex and the large number of studies on these show us the concern of teachers and researchers [1]. Most researchers have been developed in pre-university levels [2] [3], but few studies are developed at university level [4] [5]. This study is lead at university level in introductory physics for science and engineering students. Introductions of the concept work in common textbooks involve a discussion of a force $F$ applied to an object which then moves through some displacement $\Delta r$. This is followed by the presentation of the following equation or a variation thereof: $W=F.\Delta r = F. \Delta r \cos \theta$. However, many textbooks use general statements like “$\Delta r$ is the displacement of the object” or simply “the displacement,” without identifying what is being displaced. In relation to the term “force”, it often occurs that there are multiple forces acting on the system. In these cases it is necessary to discuss how to calculate the net work of all forces. Often, instructors and textbooks focus on discussing the effects of the forces in the object but when the situation is more complex and the object is deformable, however, it is more beneficial to think about systems rather than about objects (Lindsey et al, 2009). As a result, the definition of work must be changed and it is also necessary to define the relation between work and energy by magnitudes such as “pseudo-work” [6]. During a displacement, if we consider a force acting on the centre of mass of an object, the resultant work made by the force is the magnitude called “pseudo-work”. These vagueness could lead to conceptual difficulties when students apply the definitions in different contexts such as single particles or in the study of mechanics in which the student encounters friction forces or forces applied to deformable or rotating objects [7] [8].
Taking into account the previous studies, the principal objective of this study is to identify and document specific difficulties that students displayed in the thinking and reasoning processes of the calculation of work and the application of first principle of energy in isolated systems with single particles. Our major research questions are the following:

a) What do the students understand from the concept of work in a single particle system?

b) Do students understand the work-kinetic energy theorem?

This study will focus on the description of students’ understanding of several physical concepts let teachers base decisions about their interventions in the data in order to assist afterwards student learning.

2 METHODS

2.1 Methodology

This study uses the phenomenographic research approach to investigate “the qualitatively different ways in which people experience, conceptualise, perceive, and understand various aspects of, and phenomena in, the world around them” [9]. As Marton and Booth [10] say “in phenomenography individuals are seen as the bearers of different ways of experiencing a phenomenon and as bearers of fragments of differing ways of experiencing that phenomenon” (p. 114). The students attained a description which is collective and, consequently, individual voices are abandoned.

Phenomenography deals with how different ways of perceiving and understanding the reality (concepts and associated ways of reasoning) can be considered as categories describing the reality. These categories can be observed among a great number of individuals, and as a result all these representations together indicate a type of collective intellect. “The same descriptive categories appear in different situations. The set of categories is thus stable and can be applied, even if individuals ‘move’ from one category to another on different occasions” [9] (p.195).

According to Marton and Booth [10] creating categories must follow a specific set of criteria such as: a) Each category should be clearly related to research phenomena, so that each one tells us something distinct about a particular way of experiencing the phenomenon. b) Categories must be hierarchical, or in other words, they must progress from simple to complex relations. c) The categorization system should be parsimonious, meaning that as few categories as it is reasonably possible should be explained. If the system of categories developed meets the above criteria, it will be theoretically and pedagogically useful.

In this study conceptions are presented in descriptive categories following the criteria from Marton and Booth [10]. These categories are drawn from questionnaire and interview data; there is not any attempt to “fit” the data into a predetermined categories. The categories are based on the most distinctive features that differentiate one conception from another and are presented hierarchically, reflecting increasing levels of understanding. The hierarchy of the descriptive categories demonstrates the connection between conceptions and provides a basis for decisions about teaching and assessment.

2.2 Experimental design

First of all, it must be specified that the main aim is to find out whether undergraduate students have understood the basic ideas involved in the definition of work and the first principle of energy in Mechanics. Therefore, our students at the Polytechnic College and IMH Dual Engineering School (both at the University of the Basque Country UPV/EHU) attended to classes to deepen into those concepts before we gave them a questionnaire. For the better understanding of the students, once the questionnaire had been prepared, we carried out a draft test with thirty students of first-year which confirmed that they had no problem understanding how the questions were formulated. Moreover, the aims of every question were validated by six teachers (three from first-year engineering and three from third-year physics) who fully agreed with the contents. The questions were included in the first-year students’ exams that were part of the evaluation system.

All first-year students had taken two years of physics at high school and were doing their first Physics course for students of engineering. First-year Engineering students from the Polytechnic College
The students' answers to the questions were subjected to rigorous phenomenographic analysis. This involved one member of the research team reading the students’ answers and deriving a draft set of descriptive categories for each question. The same researcher then reread the students’ answers and tentatively allocated each answer to one of the draft categories. The other researchers carried out the same task independently. Once the answers had been classified, answer allocations were compared. Any disagreement about category description or answer allocation, were resolved taking into account the students’ answer as a whole. An iterative process produced the final category descriptions that reflected similar understanding answers to each category and the differences among the categories.

The interviews were transcribed and subjected to the same analysis which is described above. Interviewers tried to encourage the students to give explanations of their full knowledge by non-directive questions such as "What do you mean by that?"; "Could you explain that further?" "Do you want to say anything else about this question?"

The questions were given in two first-year engineering courses at Polytechnic College (N=123) and IMH (N=42). As the results do not differ significantly they have been grouped together.

The first two questions dealt with the definition of work and the concepts that are involved in it. These questions required to recognise the forces involved in the problem as well as their trajectory. It is also necessary to specify the concepts that are in the definition of work deeply. For example, question Q1 deals with a basketball player jumping in which the aim is to calculate the work done by the force of the Earth on the player until he reaches to the highest point.

Q1.- What is the work done by the force of the earth on the basketball player when he reaches the highest point to throw the ball? (See picture)

Explain your answer.

The students should explain how to do the calculations of the work done by the force. One of the students answered correctly as it is given below:

"The work that the force of the earth does is \( W = P \Delta s \cdot \cos 180^\circ = -P \Delta s = -mgh \). The force the earth makes on the player is the weight and taking into account that the jump is done in the opposite direction of the weight, the weight makes a negative work due to the fact that \( \cos 180^\circ \) is negative (student number 35)

About 10% of the answers of first-year students were similar to the previous one. In the next section we will analyse the alternative answers and their corresponding percentages.

The other two questions aims are to apply the principle of conservation of mechanical energy in situations of friction and/or with changing potential energy. The questions are familiar to students in the academic context and textbooks usually mentioned them as examples of work and energy. For
example, question Q3 deals with the energy principle without friction. It is required to use the principle when the applied force is not in the direction of the movement.

Q3- A box is displaced two meters due to a force of 3 N and there is not friction with the floor. The directions of the movement and force are shown in the picture:

a.- How many work does the fore do in each case? Calculate it.

b.- Which is the relation between the energy of the box and the work that it has been done on the box? How many energy of the box is changed in each case?

Only 18% of students answered the question correctly. For example:

“The relation between work and energy is $W = \Delta K$ taking into account there is not friction. The calculation of the work gives the same result of the variation of energy experimented. The work is $W=3 \cdot 2 \cdot \cos 150^\circ = -5,196$ Joules. The kinetic energy at the end of the two metres is lower than at the beginning because the work done by the force is negative” (student number 16)

3 RESULTS AND DISCUSSION

In this section we will give the results obtained in both groups of students for the two questions described above. In the discussions we will identify some conceptual difficulties which seems to be common in many students. This description of the students’ ideas will concentrate on some persistent and specific difficulties

The results of the students’ answers (N=165 in first-year of Engineering) to the two questions described in this paper are shown as percentages in table 1 and 2.

<table>
<thead>
<tr>
<th>Descriptive Category</th>
<th>Percentages of answers per category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The work the earth does in the player is correctly argued.</td>
<td>12.0</td>
</tr>
<tr>
<td>B. Alternative ideas</td>
<td></td>
</tr>
<tr>
<td>B.1 – The principle of action-reaction on the player is incorrectly explained</td>
<td>7.0</td>
</tr>
<tr>
<td>B.2 - Explications that define “no real” forces in the direction of the movement</td>
<td>33.0</td>
</tr>
<tr>
<td>Incoherent answers</td>
<td>25.5</td>
</tr>
<tr>
<td>No Answer</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 1. Results for the Question Q1
Category A includes explanations in which the force that acts on the player is the weight (due to the earth’s force) and the work is properly calculated later on. The explanations consider that displacement occur between the starting point of the jump until the maximum height is achieved.

Other three answers (2%) were classified in category A because they understand that the normal force and its work should be considered. According to this approach, these answers justify correctly that the work of this normal force is zero when the player is in the air because there is not any contact with the floor.

“The force of the ground that acts on the player is the normal force. The work that this force makes is zero because the ground has not been displaced and the normal force disappears when the is left.” (student number 13).

Category B.1. includes explanations which consider the system earth-player and analyse incorrectly the forces that act on the player as a result of applying the principle of action-reaction. There are just twelve students who answered using that principle in the wrong way, such as:

“The ground performs a force in the same direction of the displacement so the work has been done is positive. But taking into consideration the force performed by the body in the opposite direction (3rd Law of Newton), the net force is zero and consequently the work is also zero.” (student number 113).

The majority of the answers (over one third) are included in B.2. category. These explanations consider that the force that acts on the player when the jump starts is bigger than his/her weight. As a consequence, the net force is in the direction of the movement because the player rises.

“The player exerts a force in the ground and the ground returns the same force, so in my opinion the work the player does exist and it is the same that the ground does on the player. This work is done by the normal force against weight.” (student number 25)

“Incoherent” category includes answers without logical consistency or contradictory statements.

Table 2 shows the results of question Q3

<table>
<thead>
<tr>
<th>Descriptive Category</th>
<th>Percentages of answers per category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The relation work-energy is correctly reasoned</td>
<td>16.5</td>
</tr>
<tr>
<td>B. Difficulty in calculating the work and/or applying the first principle of the energy</td>
<td></td>
</tr>
<tr>
<td>B.1. Difficulty in calculating the scalar product of the work</td>
<td>11.0</td>
</tr>
<tr>
<td>B.2. Work is not understood as a scalar product of vectors.</td>
<td>13.5</td>
</tr>
<tr>
<td>B.3. They assume there is a change in the energy but they don’t justify it</td>
<td>25</td>
</tr>
<tr>
<td>Incoherent</td>
<td>10.0</td>
</tr>
<tr>
<td>No Answer</td>
<td>24.0</td>
</tr>
</tbody>
</table>

Table 2. Results for the Question Q3

About 15% of students answered correctly. However, nearly half of students (category B) show difficulties calculating the work (category B.1 and B.2) or they don’t know how to explain why the object changes its energy due to the force (category B. 3).

The difficulties in calculating the work can be classified into two standards. On the one hand, some are associated with the difficulties on calculating the scalar product (11%, category B.1). For example:

"The work is \( W = F \cdot \Delta X \cdot \cos \alpha = 5.2 \) Joules. In this case \( \alpha = 30^\circ \), because it is the angle between the force and the direction of the movement. There is an increase of energy.” (student number 29).

"The energy is increased. The performed work is \( W = F \cdot s \cdot \cos 30^\circ = 3.2 \cdot \cos 30^\circ = 5.196 \) Joules.” (student number 64).
On the other hand, 13.5% of the answers don’t take into account the vector nature of the definition of work (category B.2). For example:

"The performed work is \( W = F \cdot s = 6 \text{ J} \). The energy is increased" (student number 59)

"There is an increase in the energy. The work that has been done is \( W = F \cdot x = 3 \cdot 2 = 6 \text{ Joules} \)" (student number 46)

Students’ interest in answering the questionnaire was high as it is observed by the large number of answers and because the final mark of the course depends partially on these answers. Nevertheless, almost the quarter of the students could not answer the question. This may suggest that students don’t understand the whole meaning of the concepts involved in the relation between work and energy.

There are several common elements in the questions and in the descriptive categories given above. All questions depict situations in which the work and energy are associated with a force which is in the direction of the movement or in any other different direction. Thus, the complete understanding of the concepts involves: to understand the correct definition of the forces that acts on the system, to know how to apply the scalar product of the force vector and motion direction vector, and to understand the relation between work and energy applying the mechanical energy principle. The descriptive of categories described above reflects the level of the understanding of the students. In all questions, and particularly, in the two questions showed here, there is at least one descriptive category involving the concept of work. In almost all questions the students are asked to make relations between energy and work that should be answered by the mechanical principle of energy.

Explanations are allocated in category A if the concepts of the definition of work are properly considered and if the relation between the work that has been done and the change of energy of the system are correctly understood. As it is shown in table 1 and 2, this category is not the most frequent one. These results suggest that most students do not understand correctly neither the concepts involved in the definition of work nor the relation work-change of energy. Most of students confuse the forces that act on the system (33% in question Q1) or they do not solve correctly the scalar product between two vectors (11% in question 3). This type of difficulties, match with the difficulties of other studies in which mathematics were not properly applied in physical context. It must be highlight that students show difficulties associating a change in energy with the negative work it has been made. For instance, a significant percentage in question Q3 calculates the work done but they do not explain its influence on the change of energy of the object.

The remaining explanations were considered to be incoherent. All those explanations include rote learning that was wrongly assimilated. For example, a significant percentage of answers show an incorrect formula for the work or the value of the work is confused with the energy and not with its change. Incorrect interpretations of the way the calculations should be done are some of these inconsistencies.

Before drawing conclusions and implications for teaching, it is necessary to bear in mind that the questionnaire was carried out at two engineering schools in the Basque Country. Thus, we cannot ensure evidence for more general contexts. However, we have checked that the results obtained in this study match with results found in other studies carried out with student samples from other countries [5]. Furthermore, the obtained results present new features of the students, which showed that a significant percentage of them cannot interpret simple work and energy relations. Moreover, the results of this study also show that it is necessary to emphasise the meaning of each concept that take part on the mechanical energy principle. It would be necessary to define the system and the forces that act on it and to analyse the described trajectory by the object in the first place. Afterwards, it could be easier for the students to apply the mechanical energy principle and to calculate the work. We suggest that research with the aim of designing didactic materials and implementing them afterwards with students is necessary in order to reduce the gap between teaching mechanical energy principle and the understanding of it.

REFERENCES


