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Learners' Understanding of the term energy and its related concepts

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Abstract

The aim of this work is to find out how students construct these three related concepts: Energy, work and force, and understand the concepts: potential energy of electrons, heat and temperature, and energy flow. Indeed, this work conducted by administering a questionnaire to 64 students, at the faculty of science and techniques of Fez, Morocco. To identify Students' misconception, we analyzed the obtained results by Subject Package for Social Science (SPSS). On one hand, the findings revealed that students focus on the concept of force more than on the concept of energy or work and do not make any links between them, which indicates that these concepts are poorly constructed in the student's mind. On the other hand, we notice that Students have difficulties to understand the change of the potential energy of electrons from one energy level to another. Besides, instead of responding from an energy point of view, students use the force concept to describe a situation about energy. In addition, we have notice that many students confuse the two concepts heat and temperature. These misconceptions about energy and its related concepts are an obstacle to understanding the electron fluxes and therefore energy fluxes which are the basis of energy transduction in living cells.

Keywords

Learners' Understanding, Concepts, Energy, work, force, potential energy, heat and temperature, energy flow.

Introduction

Biological sciences contribute to the actual formation of the learners, as they focus on methods and techniques that enable the learner to build scientific concepts; the learning of biological concepts enables learners to acquire the skills of interpreting some observations or experiences, understanding principles, laws and theories, and explaining biological phenomena. However, learning scientific concepts are not without difficulties because scientific concepts vary in types, simplicity and complexity.

Energy is one of the abstract scientific concepts that are difficult to understand because its construction in the classroom requires the use of the concrete, that is to say the effects that energy can produce (Park et al.,2021;Sebastian,2017). Energy is an important concept in teaching and learning of biology. Indeed, Biology describes all the processes that take place in the living world and that based on the flow of energy in living cells (Sebastian et al.,2017)Thus, virtually all energy transductions in the cell can be related to a flow of electrons from one molecule to another (David et al., 2008). That why, students should have a basic knowledge of the energy of the electrons, which are the basis of all biological phenomena (respiration, photosynthesis, digestion…).

A lack of basic knowledge about energy, knowledge that starts from energy at the electron level, causes necessarily misconception of biological phenomena, which depend on a flow of energy. So, wrong knowledge that we have causes misconceptions while learning new aspect (KURTULUŞ et al., 2021). In fact, the wrong knowledge causes tenacious misconceptions that resist to extinction and persist at university level studies (Soehartoet al., 2019). Identification of these misconceptions is required, and then an analysis that identifies the obstacles to the construction of knowledge is needed. Thus, the starting point of all educational interventions is the

identification and then the confrontation of the wrong conceptions, which provoke in the learner a destabilization leading to the search for a new balance (Halim et al., 2018).

Moreover, the scientific definition of energy is the capacity of a system to produce work, this definition link energy to work, that is to say the possibility for a system to undergo a displacement under the action of a force. It is no more possible to learn about energy without first learning the basic concepts force and work (Bächtold, 2018). Starting from this definition of energy, we define the particular kinds of energy explicitly in terms of the work (potential energy, heat, etc.) (Bächtold, 2018). Thus, it is necessary to be aware of the basic concepts of force and work to understand energy and then these different forms. Besides work and force, potential energy is another important concept in biology. The previous studies (Cooper et al., 2013; Nicole et al., 2014) find that students have difficulties to understand the change of potential energy that occur during bonding and molecular interactions. Another form of energy: heat, on which various studies have carried out. They have looked at this concept by showing that many students could not explain the differences between heat and temperature (Suliyanah et al., 2018).In our study, we looked to know how the concepts of force, work and energy are constructed in students mind. Then we examined student's knowledge about the potential energy of electrons. After that, we analyze the misconception that student have about heat and temperature. Finally, we tested the learner's understanding of the energy flow in the living cell. In other words, we investigate how students understand energy at the electron level and how they perceive the related concepts of energy: Force, Work, potential energy of electron, Heat and Temperature, and Energy Flow. In order to identify and provide systematic analysis of the students' misconception of energy and its related concept a questionnaire consisting of both closed and open-ended items was administered to the third-year biology students. Most of the above concepts are investigated separately in the literature, in our side we analyze all the concepts cited above in biological field. We have concluded that the understanding of all these concepts together is necessary to understand energy flow in the living cell, which is the basis of all biological phenomena (respiration, photosynthesis, digestion…).

Materials and Method

This survey was carried out among Undergraduate Biology Students whose topic of energy was studied in the first year at the faculty. We opted for the questionnaire, which is a data collection instrument. It is very useful for collecting several pieces of information in a short time on a given topic or on the ideas, opinions and conceptions of people. Unlike the interview, the subjects are unlikely to be influenced by the interviewer's reactions to their answers since they answer a questionnaire individually. We therefore chose this method since it makes it possible to reach a large number of students, which corresponds to a good sample for a study. Thus, it is possible to bring out the most common ideas and to reduce the margin of error. A five-item questionnaire consisting of open and closed questions has been used as a data collection tool in the study. The questionnaire includes questions about the Use of concepts: work, force, energy, potential energy of electrons, Heat and temperature and energy flow. The sample consisted of 65 students third-year biology students.

Data Analysis

The findings have been examined in headlines of Use of concepts: work, force, energy; potential energy of electrons; Heat and temperature; and energy flow. For close items, the answers have been collected under correct and wrong categories. For the open-ended items, the answers that explaining the expected reasoning are considered correct, the answers that giving a part of the reasoning are considered incomplete, the answers explaining a false reasoning are considered incorrect; the justifications based on external elements are considered irrelevant and equated with erroneous answers.

Results and discussion

We will present the results of this study and their discussion according to the four categories indicated above.

Use of the concepts: Work, force and energy

We define energy as the ability of a system to do work, this general definition is not very satisfying but different forms of energy (potential energy, heat, etc.) are directly linked to it. In other words starting from this definition, we define the particular kinds of energy explicitly in terms of the work (Bächtold,2018).Thus, the progressive construction of the concept of energy in the classroom requires starting from the concept of force and then the integration of another concept that of work (Zeynep 2018).

In biology, the construction of the concept of energy requires a passage through the two concepts of work and force; the concept of work applied more broadly, it encompasses multiple functions such as the work, which is exerted against a force encountered in the cells or the organism. Therefore, it is no more possible to learn about energy without first learning the basic concepts force and work (Eugene, 2019).

In this category, we want to test the mental representation of students and know if they link these concepts by asking them to choose the concepts (force of attraction, Work, Energy) which allow the electrons to remain in orbit around the nucleus of the atom; student's responses are shown in Table 1.

Table 1. Students' answers about the choice of concepts

Answers of the students	Number of students	(Percent of student)
force of attraction	36	55,4%
Work	0	0%
Energy	25	38,5%
Energy et force of attraction	4	6,1%
Total	65	100,0

From Table 1, it is seen that more than half of the students say that only the force of attraction allows the electrons to be maintained around the nucleus. While 25 students declared that the energy keeps these electrons in orbit, only 4 students say that to keep electron in their orbit you need energy and force of attraction, and no students has chosen work or the three concepts together. Indeed, the attraction force allows the electrons to be maintained around the nucleus but it is necessary to against this attraction and this requires work just as we have to do work to hold an object in our hand against the attraction of gravity.

From these results, it appears that these three related concepts are poorly constructed in the student's mind since they focused on the concept of force of attraction then on the energy while none of the students chose the work or the three concepts together. This indicates a conceptual difficulty in the student's mind on energy and its related concepts. These conceptual difficulties

of energy, work and force are coming from a bad construction of links between energy and its basic concepts.

Potential energy of electrons

Understanding the potential energy of electrons is the first step to understand the fluxes of electrons, which are the basis of energy transduction in living cells. Potential energy at the macroscopic and the atomic–molecular levels was treated in (Cooper et al., 2013); it has been proofed that students cannot develop a coherent understanding and explicit connections from the macroscopic to the atomic – molecular level. Most of the previous studies (Cooper et al., 2013; Nicole et al., 2014; Nicole et al., 2018; Kohn et al.,2018) asked students about their understanding of the changes in the "potential energy'' that occur during bonding and molecular interactions. They do not seek how they understand the changes in the potential energy of electrons from one energy level to another which seems the basis for understanding the potential energy changes of a system as two objects (atoms or molecules) approach one another.

In this category, we proposed three situations. Firstly, we tried to find out how the students

understand the potential energy of electrons as well as their ability to reason by analogy going from a situation on the macroscopic level to a situation on the microscopic level. For that, we have proposed a situation at the macroscopic level involving the concept of potential energy, from which the students must make an analogy to describe a situation at the microscopic level. The proposed situation is that of an apple placed on a table and therefore has a potential energy of position and to move it against the pull of gravity it is necessary to perform a work with the hand, which increases its potential energy. Therefore, Students must mobilize this situation to describe the case of an electron having a potential energy of position relative to the nucleus of the atom. Student's responses are shown in Table 2.

From table 2, it's seen that only 2 students correctly explained the requested situation by mobilizing the elements of the proposed situation. Indeed, moving an electron to higher energy levels requires an input of energy that increases its potential energy. According to the incomplete answer, 6 students do not fully describe how the electron moves away from the atom this is proof that they don't have enough information. When wrong answers are examined, it is seen that 12 students consider the force of attraction of the nucleus as the energy supplied to displace an apple by the hand against the pull of gravity. The common difficulty is that they use force instead of energy. The main reason for this is that before the students understand related concepts with energy such as force; they try to comprehend the energy concept. So, students cannot define this concept clearly and they use related concepts instead of it. Therefore, students find difficulties to understand how potential energy change.

Table 2. Students' answers about Potential energy of electrons

Categories of responses	**Answers of the students**	**Number of students (n = 65)**	**Percent of students**
Correct	If we provide energy to the electron, it will move from one orbital level to another by excitation, then its potential energy increases.	2	3,07%
incomplete	If we provide energy to this electron, its potential energy increases	6	9,2%
Wrong	The potential energy of electrons increases as they approach to the nucleus due to the force of attraction of the latter and decreases as they move away from the nucleus.	8	12,3%
	The force of attraction of another nucleus increases the potential energy.	4	6,15%
	The potential energy of the electron does not change	1	1,5%
	Unrelated	8	12,3%
Unanswered	Unanswered	36	55,4%

Secondly, we asked students about the potential energy change of electrons from an energy level to another by using a diagram that shows the energy levels of the atom. Students' responses are shown in Table 3. The results obtained from table 3 confirm the students' misconceptions found in the first situation,Its show that, more than half of students gave wrong answers, saying that the potential energy of the electron decreases when it goes from a lower energy level to a higher energy level. 25 students provide a correct answer saying that potential energy increases from a lower energy level to a higher level. These results confirm the misconceptions of the some students founded in the previous category who said that the force of

attraction attracts electrons towards it, which increases their potential energy and shows that most students think with the same way.

In addition, we asked students about the direction of movement of the electron when it absorbs light energy. Student's responses are shown in Table 4.

Table 3. Students' answers about the potential energy change of electrons from an energy level to another.

Categories of responses	**Answers of the students**	**Number of students (n = 65)**	**Percent of students**
Correct	Potential energy increases from a lower energy level to a higher level.	25	38,5%
Wrong	the potential energy of the electron decreases when it goes from a lower energy level to a higher energy level	36	55,4%
Unanswered	Unanswered	4	6,15

Table 4. Students answers about the direction of movement of the electron when it absorbs light energy.

Categories of responses	**Answers of the students**	**Number of students (n = 65)**	**Percent of students**
Correct	the electron will move in the direction 2 i.e. towards a higher energy level	40	61,5%
Wrong	the electron will move in the direction 1 i.e. towards a lower energy level	25	38,5%
Unanswered	Unanswered	0	0

Thirdly, we asked students about the direction of movement of the electron when it absorbs light energy. 40 students gave a correct answer by saying that the electron will move in the direction 2 i.e. towards a higher energy level, and 25 of the students gave an incorrect answer saying the opposite i.e. the electron will move towards a lower energy level . Therefore, most students know that light excites electrons and the latter moves away from the nucleus. However, they do not know that this energy supply (light energy) increases the potential energy of the electron. This shows an incoherent understanding and therefore the students find themselves unable to develop a coherent understanding of the electron flows, which are the basis of the transduction of energy in living cells.

Heat and temperature

The concepts of heat and temperature are closely related and are always presented together to learners. These concepts seem to cause many difficulties for the students. Indeed, several studies on students' conceptions of heat and temperature show that the majority of them confuse the two concepts (Alwan, 2011; Ratnasari et al.,2017; Sozbilir,2003).

In this category, we asked students if temperature is a measure of heat and explaining why. Students' responses were presented in Table 5 and students' explanation were classified in Table 6.

Table 5. Students' answers about if temperature is a measure of heat

Categories of responses	Answers of the students	Number of students (n = 65)	Percent of students
Correct	Temperature doesn't measures or quantifies heat	19	29,2%
Wrong	Temperature measures or quantifies heat	46	71%
Unanswered	Unanswered	0	0

Table 6. Students' explanations about if temperature is a measure of heat.

Categories of responses	Students' explanations	Number of students (n = 65)	Percent of students
Correct	Do not have the same heat despite the same temperature, we can take a container of 2L at 100 ° c and a second of 200L at 100 ° c, they have the same temperature but do not have the same amount of heat.	3	12,2%
incomplete	0	0	0
Wrong	Temperature is the amount of heat	8	12,27%
	heat is high temperature	8	12,27%
	heat and temperature are the same	6	9,23%
	Temperature is the amount of heat	5	7,69%
	There is no relation between the two concepts.	4	6,15%
	Heat is a variation of temperature	3	4,61%
	it's a positive temperature	2	3,07%
	The T measures the degree of heat	2	3,07%
	Unrelated	1	1,53%
Unanswered	Unanswered	21	32,30%

From table 5, 70% of students mention that temperature measures or quantifies heat, indicating that the majority of students confuse the two concepts. From table 6 where student gave their explanation to their answers mentioned in table 5. It is seen that only 2 students gave a correct reason by saying that the two containers that have different volume of water with same temperature do not have the same amount of heat or by saying that the temperature is not a measure of heat but of its intensity.10 students gave wrong answers. Among them 2 students think that Temperature is the amount of heat. 2 students said that we measure either heat or cold as a function of temperature.8 students said that heat is a positive temperature. 6 students said that heat is high temperature. 2 students told that heat and temperature are the same. 5 students said that temperature measures the degree of heat. 2 student told that the temperature measures the amount of heat. 2 student said that Heat is a variation of temperature. One student told that there is no relation between these two concepts. All the above answers are not corrects which indicate a misunderstanding of these concepts. The findings revealed that many students confuse the concepts of heat and temperature.

Our results was likely similar to the conceptions found by (Erickson, 1985).He found the following misconceptions: Heat is hot, but temperature can be cold or hot, there is no difference between heat and temperature, which indicates that these conceptions persist among students.

Other students say that temperature is a measure of the degree of heat; this misconception leads students to believe that two objects of the same temperature have the same amount of heat. Others say that we measure heat or cold as a function of temperature, so students believe that heat and cold are separate entities rather than the same concept. However, some of these students viewed temperature as the amount of heat. However, some of these students consider temperature as the amount of heat; this misconception is the same as that found by (Kesidou & Duit, 1993) so they think that two different quantities receiving the same amount of heat have the same temperature. Others say that heat is a change in temperature instead of saying that the change in temperature is an observable effect of heat transfer.

Energy flow at the cellular level

Almost, all of the energy transductions in the cell can be related to the flow of electrons from one molecule to another. In our work, we tried to test the students' understanding of the energy flow in the cell. For this we asked the students to answer from an energetic point of view, why the oxidation of glucose is not done in a single step by the cell, by indicating the considerable amount of energy released at the end of this process (2840kJ / mol) . Students' responses were classified in the categories presented in Table 7.

Table 7. Students' answers about Energy flow at the cellular level

Categories of responses	**Answers of the students**	**Number of students (n = 65)**	**Percent of students**
Correct	If the oxidation is done in one-step, it can be unfavorable for the cell.	8	12,3%
incomplete	0	0	0
Wrong	Unrelated	21	32,3%
	Unanswered	36	55,4%

From table 7 we found that 4 students provided an answer considered as correct. They say that From table 7 we found that 8 students provided an answer considered as correct, these students are aware that this large amount of energy is harmful to the cell. However, most of the students gave unrelated answers or have not answered this question. This is due to the student's misunderstanding of the atomic-molecular level. Also, they have a hard time connecting information from the macroscopic to the atomic-molecular level. Therefore, the key to understanding the flux of energy is to know how electrons move from one energy level to another. The amount of energy of an electron depends on its orbital position or energy level around the nucleus of the atom. When an electron is removed from one atom and given to another, the positional potential energy of the electron is also transferred. For instance, in the oxidation of glucose, electrons in the C-H bonds of the glucose molecule are eliminated in stages in a series of enzymatic reactions called glycolysis and the Krebs cycle. During the oxidation of glucose, the electrons fall into lower energy levels in stages, releasing stored energy which generates ATP. Therefore, students should know that when electrons move from one energy level to another, they release energy gradually rather than releasing all the energy in one explosive step which causes combustion of the cell.

Conclusion

Due to the concept's relevance in science, energy is considered as a core (or big) idea for

the teaching and learning of biology. All biological phenomena (respiration, photosynthesis..) are described in terms of energy; all living organisms collect energy from chemical bonds. Therefore, we must first learn the energy changes at the level of electrons to then understand the potential energy changes of a system when two atoms or two molecules come together (chemical bond); misconceptions at this level prevent students from understanding how energy flows at the cell level.

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