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Basic Laws of Thermodynamics and the Influence of Vitalistic Conception on Learning of the High School Students About Matter Cycle and Energy Flow

Fulya Öztaş

Vocational High School of Health, Selçuk University, Konya, Turkey

Abstract: This study analyzes whether the basic laws of thermodynamics or vitalistic conception is effective in explanation of the matter cycle and energy flow in an ecological system by the high school students. The findings of the study suggest that although the students know the physical and chemical laws about matter cycle and energy flow as well as the second law of thermodynamics on theoretical basis, they are faced with some difficulties arising from the vitalistic conception in applying to the biological facts.

Key words: Matter cycle, thermodynamic, energy flow, ecosystem, secondary education

INTRODUCTION

It has been known for a long time that the students experience some difficulties in understanding that the matter cycle and the energy transfer are done according to the basic laws of thermodynamics. Morowitz (1992) agreed that there are some conflicts in applying of the basic laws of thermodynamics on biological events. Energy and matter cycle are known to be difficult to teach in science courses and known to be the main reason for several misconceptions (Barak *et al.*, 1997). The fact that the subject of energy is taught in different formats and different purposes for living and non-living things in physics, chemistry and biology courses results in some problems in applying of energy to such disciplines. This causes some problems in understanding the energy storing between the bonds of organic molecules which form the basis of the vitality and their use without loss in living systems which are accepted as a closed system (Dobzhansky, 1974). The evolutionary studies suggest that the biological systems differentiated in non-living molecules such as organic molecules at first to create the primitive forms and then the developed living forms. However, the fact that the molecules come together according to certain physical and chemical laws and whether such organization causing the living variations depending on energy can emerge on its own or not has long been debated. According to the Law of thermodynamics, in closed systems such as the living things, the disorder tends to transform to order. Is it possible that such organization emerges on its own depending on the biological energy, or is there an external vital force playing role in organization of such molecules in a living thing which come together with physical and chemical laws (Wilson, 1992)? At this point, the scientists as well as the religious circles commonly used the

vitalistic conception in explaining the necessary force to transform an organized matter to a living things. It was generally accepted that an external factor activated the organic molecules and created vitality. In the following years, this conception formed the basis of the opinions that the second law of thermodynamics could not explain the formation of vitality (Bridgman, 1961; Lehninger, 1971; Harold, 1986). Despite the ongoing debates, it has been accepted that the molecular structure of the living things as well as their operation and the emergence of vitality is in accordance with all physical and chemical laws (Bera, 1982; Jeffrey, 1987; Elitzur, 1994). It is known that a vitality definition which is not secure, mostly based on the traditional doctrine is developed in individuals starting from the childhood and such definition usually includes religious and anthropomorphic elements. (Tamir and Zohar, 1991). It is known that the biological education cannot reach to the desired point due to the reflection of the views about livingness that include vitalistic elements acquired outside school (family, environment), on the biological education (either by teacher or student) (Lawson and Worsnop, 1990; Lawson and Weser, 1992). Barak *et al.* (1997) and Solomon (1987) suggested that the students may fall in dilemma based on the vitalistic conception in application of the second law of thermodynamics to basic ecological events such as matter cycle and energy flow in biological education.

Therefore, this study analysis whether the basic laws of thermodynamics or vitalistic conception is effective in explanation of the matter cycle and energy flow in an ecological system by the 9th grade students.

MATERIALS AND METHODS

Study pattern: This study has been performed within the scope of phenomenology pattern which is a qualitative

research pattern. In phenomenology studies, it is generally aimed to reveal the individualistic perceptions or perspectives regarding a certain phenomenon and to interpret the same. The questions have been open-ended to allow the students to answer them in a wider spectrum. Open-ended questions are more commonly used in determining the understanding levels of the concepts as well as the misconceptions (White and Gunstone, 1992).

Sampling and the test application: This study has been performed in Turkey, between 2006-2007 that totally forty-four 9th Grade students (average age 14) all of whom were enrolled in the Anatolian High School they currently study at after an eliminative test. The students have been taking basic chemistry and physics besides biology in the 9th grade and since they were accepted to such classes after an eliminative test, it has been accepted that their level of knowledge is approximately equal. In order to measure the basic knowledge of the students about the matter cycle and energy flow and ecological diagram including sun, plants, algae, fish, fish skeletons, bacteria and fungi has been presented to them. This diagram has been arranged after scanning the diagrams and texts of ecology chapters of the high school biology books and it has been confirmed to be suitable for 9th grade students after being reviewed by three specialists working on ecology before applying the diagram. The students have been asked the following questions regarding the diagram:

- The events about the matter and energy cycle observed in the ecological diagram
- Whether the vitality can be explained through physical and chemical laws by observing the events in the diagram
- Whether the concept of energy is the same in physics and chemistry and biology observing the ecological events in the diagram and if there is a difference, how can it be explained
- According to the diagram to what forms the energy from the sun transforms and what events does it trigger?

The three ecological specialists have examined the questions in terms of the reliability of their content and concluded that the questions could allow the determination of the basic opinions of the students with regard to matter cycle, energy flow and thermodynamics.

Data analysis: The contents of the responses given by 44 students have been analyzed and the responses have been analyzed in terms of whether they include basic laws of thermodynamics and/or vitalistic conception in

explaining the matter cycle and energy flow according to a response key prepared by three academics specializing on the subject. The responses of true, partly true and false that are close in meaning are shown in Table 1-4 as grouped according to percentage and frequency distribution. For instance, the expression, the plants produce chemical energy through photosynthesis, the animals transform it to mechanical energy, the bacteria and fungi decompose the fish and transform into organic matter which in turn is used by the plants again has been accepted as true and assessed in the same category with similar responses. Similarly, the expression the fish aspirate through the oxygen molecules in water and produces ATP. The chemical energy decomposes the death fish. The death fish are resolved by the bacteria and fungi has been accepted as true but incomplete. In the outer structure of the living things physical changes are observed while in the inner structure there are chemical changes. Such expression has been regarded as false, because the student thinks that the origin of the chemical and physical energy is different.

A scale between 1-4 has been used in assessment of the open-ended questions and if the response of the student is sufficient in terms of conceptual understanding it gets 3 points, if it is partly true it gets 2 points, partly responses including false responses get 1 point and no response gets 0 point and the reliability co-efficient has been found as Cronbach $\alpha = 78$.

RESULTS AND DISCUSSION

It is highlighted in biological education that the living systems operate in accordance with the physical and chemical laws and that particularly the second law of thermodynamics is applicable to biological systems. It has been seen that although they mostly know that the vitality is formed by elements and molecules, they ignore that these should operate in accordance with the basic laws of thermodynamics. Therefore, it is known that the students seek a vital force having a metaphorical nature in explaining some events in growth, development and reproduction of the living things. It has been found that some of the students suggest that events such as respiration, enzyme synthesis and embryonic development cannot only be explained within physical and chemical laws and that a different force may be in place regarding vitality (Hogan and Weathers, 2003). The results from the studies suggest that there is a relationship between the students' understanding of biological energy and the second law of thermodynamics and the vitality. For this reason, the fact that the origin of the energy used in living systems is not understood by the students forced them to seek another force to provide

vitality. Although most of them seem to believe that the biological systems operate in accordance with the physical and chemical laws, a considerable number of students ignore these in explanation of the biological events, which lead to misconceptions. At this point, it is important that the teachers and the students only focus on the biological information to explain biological events and ignore the basic physical and chemical laws.

Table 1 shows the students' matter and energy cycle and interpretations and it is shown that 36% of the students have the basic knowledge about the general purpose of photosynthesis, use of photosynthesis products and ATP formation as a result of respiration and energy use in decomposition process. Thirty two percent of another student group has shown that they know that chemical energy is produced by photosynthesis and this is transformed into other energy forms and bacteria and fungi play role in producing organic matter as decomposers and such organic matters are used by the plants again, which indicate that they know the main properties of matter and energy cycle in biological systems. With a categorical approach, 21% of the students summarized the basic events seen in matter cycle, which shows that most of the students have basic knowledge about matter cycle and energy flow in ecological systems. It is seen that the students talk about physical and chemical energy types as for the origin and types of energy and the fact that they have talked about organic molecules and ATP production shows that they know about the energy types used in biological systems. In general, ATP is a chemical molecule associated with energy by the students and attracts interest because of the energy it has. However, it has been known for along

time that there are some difficulties in understanding that ATP and the basic components of the cells operate according to the basic laws of thermodynamics (Gayford, 1986). There are some misconceptions about the origin and use of energy, as some of the students have suggested that chemical energy results from chemosynthesis and the physical energy results from decomposition, which support the previous findings.

Table 2 shows that 52% of the students use such expressions that suggest that humans have a superior organization and so the growth and development in the living things cannot only be explained with physical and chemical laws. Contrary to this, 32% of the students have used expressions suggesting that vitality can be explained with physical and chemical events and 16% of the students stated that outer structure of a living thing can be changed physically while the inner structure changes chemically (misconception).

Although, the students accept that the vitality can be explained with physical and chemical laws in general, it has been known that there are some problems in explaining the relationships between maintenance of matter and vitality (Barak *et al.*, 1997). Thus, the students have been asked whether the growth and development can be explained through chemical and physical laws and most of them have said that growth and development in living things cannot be explained through physical and chemical laws. The students seem to believe that vitality can only be explained with biological laws, which can be seen as a reflection of the vitalistic conception. A reflection of the conception that growth, development and reproduction in living things is performed by a vital force may emerge as the view that growth and development in

Table 1: The frequency and percentage distribution of students' views about matter and energy cycle

Categories	Mean answers	Frequency	Percentage
The sample for correct answers	Plants product chemical energy via photosynthesis. This converts into heat and mechanical energy in animals. Bacteria and fungi decompose fish and convert into organic matter and those substances use for matter cycle in plants	14/44	32
The samples defect but, correct acceptable answers	Via photosynthesis plants product food and oxygen. Fish use this oxygen for respiration and product ATP. Chemical energy use by fish, bacteria and fungi	16/44	36
	The diagram has been showing some biologic events such as food chain, respiration and decomposition. The plants benefit from solar energy, fish benefit form chemical energy	9/44	21
The sample for wrong answers	The chemical energy come from chemosynthesis, mechanical energy come from decaying process	5/44	11

Table 2: The frequency and percentage distribution of students' views about whether the growth and development can be explained through chemical and physical laws

Categories	Mean answers	Frequency	Percentage
The sample for correct answers	Yes, the growth and development can be explained through chemical and physical laws because, physical, chemical and biological energy is the same. The growth, development and decomposition on alive occur depend on physical and chemical events	14/44	32
The sample for wrong answers	Biological systems such as humans have a superior organization and so the growth and development in the living things cannot be explained with physical and chemical laws. Only can be explained with biological laws	23/44	52
	As the physical changes affect the outer structure of the living things, chemical changes affect only the inner structures of them	7/44	16

living things cannot be explained through physical and chemical laws (Toulmin and Goodfield, 1962). As it can be shown from Table 2, the fact that the students suggest that biological events cannot be explained by physical and chemical laws demonstrate that the students cannot sufficiently adapt the physical and chemical laws applied for matter cycle and energy flow to the biological events. The fact that some students think that physical changes affect the outer structure of the living things while chemical changes affect the inner structures may be an indication of the effectiveness of a vitalistic and pre-determinant teleological view.

In Table 3, it is shown that 50% of the students defend that energy cannot exist out of nothing and cannot disappear while being in existence and thus both forms of energy are the same. However, it is seen that 32% of the students suggest that physical energy results from physical events and the chemical energy is the inner energy of the living thing, which is contrary to the second law of thermodynamics. Some students have put forward that the energy in biology is generated from the living things while the energy in physics is generated by the generators and power sources. Some of the students (18%) have been indecisive since they have not been sure about what they know. So, they have suggested that the energy used in physics is related to performing job, biologic energy is for continuity of life.

The statements such as the energy comes from the breaking molecules may result in that students think such energy as the physical energy (material energy) while the expression the living things get their energy from nutrition may be perceived as the biological energy. The fact that the subject of energy is taught for different purposes and with different examples for physics, chemistry and biology, may result in different perception of energy for different disciplines (Solomon, 1983, 1987; Gilbert and Pope, 1986; Mark and Young, 1987; Kesidou and Duit, 1993; Barak *et al.*, 1997). The findings demonstrate that the students tend to accept the biological energy as instinctive force while they perceive physical energy as external energy, which very much resembles the vitalistic conception. The vitalistic conception was used in explaining the non-living systems acquiring vitality in the

old times and according to this theory, an external vital factor activates the organic molecules in the living things and form vitality. Therefore, it is possible to think that there may be similarities between the inner energy as defined by students and the vital force suggested by the vitalistic conception. Previous findings support such idea (Jacob, 1993). A true knowledge regarding the physical and chemical properties of energy is very important for biological education. This is because in some stages of learning, it has been suggested that predetermination and anthropomorphic approach are common among students (Lawson and Weser, 1992; Tamir and Zohar, 1991) and that vitalistic conception may appeal to the students (Elitzur, 1994). As a supporting view, Carey (1985) defended that biological theories arise from the human behavior while the physical laws result from the nature of the physics and Chi (1992) suggested that the nature of ontological change makes the learning of physics different from biology and thus these should be taught differently. Barak *et al.* (1997) talked about some biological events which are said to be in conflict with the second law of thermodynamics and Dobzhansky (1974) suggested that these can all be explained through the entropy theory of thermodynamics. It has been suggested that the students believe that the development, reproduction and biological systems are instinctive in humans, but they have difficulty in explaining such mechanisms (Toulmin and Goodfield, 1962). The findings suggest that although the students accept that the biological energy is used in vital activities of the living things, they do not practically use expression such as inorganic and organic molecules are automatically organized with the help of the biological energy in line with the non-vitalistic conceptions (thermodynamic laws).

According to Table 4, most of the students (43%) put forward that sugar is produced as a result of photosynthesis and this is stored as a starch and 23% of them explain the process scientifically and suggest that solar energy (physical energy) is transformed to chemical energy and stored and this is used as mechanical and heat energy. In general, 18% of them put forward that energy is stored in chemical bonds and 16% of them suggest that the energy from the sun is not stored in animals.

Table 3: The frequency and percentage distribution of students' views about whether physical energy concept and biological energy concepts same or different?

Categories	Mean answers	Frequency	Percentage
The sample for correct answers	Both forms of them are same because, energy cannot exist out of nothing and cannot disappear while being in existence	22/44	50
The samples for wrong answers	Both form of them different each other because, physical energy results from physical events such as water, wind etc. and the chemical energy is the inner energy of the living things	14/44	32
	Almost both of them are same, as physical energy is related to performing job; biologic energy is use for continuity of their life	8/44	18

Table 4: The frequency and percentage distribution of students' views about storage of solar energy in plants

Categories	Mean answers	Frequency	Percentage
The sample for correct answers	Sugar is produced as a result of photosynthesis and this is stored as a starch in leafs	19/44	43
	Solar energy (physical energy) is transformed to chemical energy and stored and this is used as mechanical and heat energy	10/44	23
	Solar energy is stored in chemical bonds	8/44	18
The sample for wrong answers	Energy from the sun is not stored in animals	7/44	16

It is somehow difficult to apply energy maintenance law to biology and there are some problems in understanding that the energy stored in organic molecule bonds is used without loss in living-things which are a closed system (Dobzhansky, 1974). Different circles discuss about the fact that organic molecules come together from the non-living molecules in accordance with certain physical and chemical laws and that the living organization come about by itself depending on energy. It is also suggested that the use of such terms as liquid energy, energy making leads the students to believe that there is a partial energy loss in matter cycle, as in the interpretation of the second law of thermodynamics (Solomon, 1983; Kesidou and Duit, 1993). The findings have shown that the students have true knowledge about the storage and use of energy in general sense.

CONCLUSION AND RECOMMENDATIONS

The findings of the study suggest that although the students know the physical and chemical laws about matter cycle and energy flow as well as the second law of thermodynamics on theoretical basis, they are faced with some difficulties in applying to the biological facts. As similar to the results of the previous studies (Barak *et al.*, 1997), it is seen that the vitalistic conception is more widespread than assumed among the students. The fact that energy is not generally defined in physics, chemistry and biology and energy is taught differently for different disciplines may be the main reason of misconceptions among students.

The findings of research showed that the origin of the energy used in living systems is not understood well by the students that forced them to seek another force to provide vitality. It seems that most of them seem to believe that the biological systems operate in accordance with the physical and chemical laws, but it has been detected that a considerable number of students ignore these in explanation of the biological events, which lead to misconceptions. At this point, it is important to advise that the teachers and the students not should only focus on the biological knowledge to explain basic biological events; they should not ignore the basic physical and chemical laws during explaining biological events. The findings of study suggest that a true knowledge regarding

the physical and chemical properties of energy is very important for biological education that should not disregard during teaching process. Because students tend to accept the biological energy as instinctive force while they perceive physical energy as external energy, which very much resembles the vitalistic conception.

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