ISSN 1648-3898 Journal of Baltic Science Education, No.1, 2003-03-20; pp. 21-27.

WHAT STUDENTS' UNDERSTAND FROM ENTROPY?: A REVIEW OF SELECTED LITERATURE

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Abstract. This study is intended to review some of the selected researches carried out on students' understandings of entropy. The review puts together the important findings of the researches, summarises the misunderstanings identified together with the possible sources of these misunderstandings and new approaches in defining entropy. Therefore, this study would be beneficial for the researchers and lecturers in science and chemistry education area.
Key words: misunderstandings, entropy, tertiary education.

Introduction

Ever since the classical studies of Piaget, there has been an interest in the conceptions of physical science held by young children (Osborne, 1983). Even a casual observer of the field of science education over the last two decades knows that this has been a period of unprecedented exposure of the ideas held by children, adolescents, and to a lesser extent adults, about a wide range of scientific phenomena (Griffiths, 1994). Research in this domain has attempted to answer questions such as which misunderstandings occur, what are their origins, how extensive are they and, of course, what can be done about them? (Gil-Perez and Carrascosa, 1990). It is quite understandable why students' ideas concerning chemical phenomena have become a research focus. Many students from secondary level to university struggle to learn chemistry and many do not succeed (Nakleh, 1992). Research now shows that many students do not correctly understand fundamental concepts (Griffiths, 1994) and also many of the scientifically incorrect ideas held by the students go unchanged from the early years of the schooling to university, even up to adulthood (Gil-Perez and Carrascosa, 1990). By not fully and appropriately understanding fundamental concepts, many students have trouble understanding the more advanced concepts that build upon these fundamental concepts (Thomas, 1997).

Many high school and university students experience difficulties with fundamental thermodynamic ideas in chemistry (Banerjee, 1995). Despite the importance of thermodynamics as the foundation of chemistry, most students emerge from introductory courses with only very limited understanding of this subject (Ochs, 1996).

Entropy is a fundamental concept in chemical thermodynamics that helps to explain the natural tendency of matter and energy in the universe to become less ordered (Tomanek, 1994). This is an explanation of the Second Law of Thermodynamics which states that entropy increases when a chemical reaction occurs spontaneously. In general, students seem to have not problem with the second law, because it does not run against students' everyday experiments and it is in accordance with the requirements of the school science curricula.

This study intended to review some of the key research studies about students' understandings of entropy. The benefits of this study to the science education would be two folds. Firstly, it would serve a starting point for the researchers in this area and secondly, the common misunderstandings would be available to lecturers as a ready to use material.

The Review of the Selected Literature on Entropy

Students generally interpret entropy as a measure of disorder (Johnstone et al, 1977; Sozbilir, 2001). Although the recent research studies (Selepe and Bradley, 1997; Ribeiro, 1992) support this finding, there are evidences that students misunderstood the second law. Some of the misunderstandings identified are given in Table 1 and discussed below.

Table 1. The identified misunderstandings about entropy

Misunderstandings Identified	***Students' Age***	***Revealed By***
When the entropy is increased, the temperature is also increased	17 years old	Johnstone et al (1977)
When a released rubber band contracts entropy decreases		
According to the Second Law, the entropy of *the system* must increase for a spontaneous change	University	Thomas (1997)
Entropy equals to the disorder of the system	University	Sozbilir (2001), Selepe and Bradley (1997)
CO_2 has bigger entropy than C_3H_8 at the same temperature		
Entropy is the cause for the disorder in the system	University	Selepe and Bradley (1997)
Entropy shows that work has been done on the system		
A micro state is a little state, it is not related with entropy	University	Sozbilir (2001), Ribeiro (1992)
In an isolated system the change of entropy is greater or equal to zero		
Entropy of the universe does not change or decrease	University	Ribeiro (1992)
A system always goes to maximum entropy		
The change of entropy of a reaction is always positive		
Inaccurate connection of entropy to the number of collisions and intra-molecular interactions	University	Sozbilir (2001)
Inaccurate connection of the entropy of a system and the entropy changes accompanying in the surroundings		
Entropy of the whole system decreases or does not change when a spontaneous change occurs in an isolated system		

It was reported that there was some tendency to confuse entropy with kinetic energy (Johnstone et al, 1977). This confusion was explored from an easy rubber band experiment in which a rubber band at room temperature has more entropy value than when it is released. Johnstone et al study showed that nearly half of the students considered that the entropy value of released rubber band was more than its initial state, and also that its temperature must increase when it contracts in contrast to the scientific view. They concluded that "increase in entropy, therefore, seems to equate with increase in temperature, perhaps through some misconceptual notion of disorder (Johnstone et al, 1977; p.250)". Similar results were also identified by Sozbilir (2001) and Selepe and Bradley (1997). They concluded that there seemed to be a strong relationship between entropy and kinetic energy of the particles. Another misunderstanding explored by Johnstone et al (1977), Sozbilir (2001) and Selepe and Bradley (1997) resulted from a misinterpretation of the term 'disorder' as 'chaos'. The source of this misunderstanding was the point taught where a haphazard array of tumbled building bricks was accorded 'greater entropy' than the original ordered array. It was also found that the students' understanding of the word 'disorder' is different from its scientific meaning (Ribeiro, 1992). Students used disorder in the sense of chaos or randomness. It was also reported that the majority of the students considered that disorder was larger when the energy increased. Moreover, it was found that students perceived entropy and disorder as equal or that entropy was the cause for the disorder in the system (Selepe and Bradley, 1997). The study revealed that students perceived that entropy shows that work has been done on the system. Finally, university chemistry students were asked to compare the entropy values of carbon dioxide and propane at the same temperature. The results indicate students thought that carbon dioxide had bigger entropy than propane at the same temperature (Ribeiro, 1992).

In another study Ribeiro (1992) interviewed 14 Portuguese chemistry undergraduates in their final year. It was reported that although the majority of the students remembered the term microstate, only a few of number of them were able to explain it in terms of the possible arrangements of the particles. It was also found that microstate was perceived as a little state and not related with entropy. In the same study it was also revealed that students have such misunderstandings as that entropy of the universe does not change, a system always goes to maximum entropy, the change of entropy of a reaction is always positive and finally, in an isolated system, the change of entropy is greater than or equal to zero. The research suggests that university teachers should determine students' existing knowledge, lecturers should be careful in the language they use, scientific ideas must be shown to be useful to explain real phenomena and students should be helped to see clearly the contextual differentiation of their knowledge more clearly (Ribeiro, 1992).

In a study carried out in Germany by Duit and Kesidou (1988), 14 students were interviewed in order to discover 10th grade (about 16 years old) high school students' understanding of the Second Law and irreversibility. It was explored that most of the students had the correct idea that heat flows from a hot body to a cold body and that temperature differences tend to equalize. Contrary to this result, there was a considerably number of students who thought that a certain temperature difference might arise after the temperature equalisation. Their concluding remark was that students' ideas about the natural processes were mainly based on everyday experiences rather than scientific ones taught in school. In a subsequent study, Kesidou and Duit (1993) suggested two ways to overcome this misunderstanding. Firstly, the experiments should be carried out by the students and secondly a framework should be provided that conceptualises the thermal interaction as an exchange of heat that runs spontaneously as long as there is a temperature difference.

A classroom based study conducted by Tomanek (1994) in a secondary environmental science class which explored the idea of entropy in the study of basic ecology. The data was collected during 9 weeks school time by making audio recordings of all class sessions and by interviewing students. The study revealed several different understandings of entropy is developed by secondary students during this study. Some of those ideas are:

- Entropy governs matter and energy in such a way that both became less ordered and less useful for human purposes
.
- Increasing the rate of entropy decreases the amount of 'useful' matter and energy.
- Maintaining living systems increases the entropy.
- Highly consumptive life styles accelerate the entropy.
- Reducing the amounts of waste matter and waste energy that enter the environment reduce the entropy.
- Entropy contributes to the process of ecological succession. (p.79).

Tomanek (1994)'s study shows that students could develop scientifically acceptable ideas if they are taught concisely. Students involved this research learned entropy as a physical law of nature rather than an idea that matter becomes more mixed up. It was argued that it would be useful to develop tasks at the beginning of the course leading students to discuss, and confront alternative ways of thinking about entropy.

In a research with the chemistry undergraduates it was found that students were having difficulty in understanding the term '*disorder*' and '*spontaneity*' (Sozbilir, 2001). It appeared that students' understood '*disorder*' as chaos, randomness or instability in some cases. Disorder and entropy were considered as synonymous in other cases. They also thought of '*spontaneity*' as a random rapid movement or as an undirected action. It was concluded that students' tendency to use algorithm to solve the problems associated with conceptual understandings seemed to cause misunderstandings (Sozbilir, 2001). Students were also found having difficulty in differentiating the visual disorder and entropy. This most probably comes from the analogies used during teaching and also the definitions made and analogies used in textbooks (Sozbilir, 2001). Some of the misunderstandings seem to have originated from incorrect transformation of the macro-world to the micro-world of particles in spite of the fact that particles in the micro-world have been introduced for easier understanding at the level of sensation. Few students were aware of the definition of entropy; that it is *the measure of the number of ways that energy can be shared among the particles.* In addition, only a few students were aware of the microstates which are the possible ways of arrangements of particles. It appears that teaching entropy as '*a measure of disorder*' is more likely to confuse students and cause misunderstandings as discussed above. In recent studies Lambert (1999, 2002) argued that teaching entropy by using 'disorder' should be avoided as it does not help students to visualise and conceptualize entropy accurately.

What Should We Teach About Entropy?

In recent years a series of papers produced about entropy challenging the current definitions of entropy together with the weaknesses of them in the textbooks. In these papers, Lambert (1999, 2002a, 2002b), difficulties associated with teaching entropy though 'disorder' was discussed and possible alternatives were provided about the definition of entropy. It was argued that entropy could be considered from two viewpoints, classical thermodynamics and mechanical thermodynamics. From a classical thermodynamic views point, entropy can be seen as a measure of the dispersal of energy from localised to spread out. In molecular thermodynamics point of view, it can be considered as the change in the system from having fewer accessible microstates to having many more accessible microstates (Lambert, 2002b). However, it was also argued that teaching entropy as 'disorder' is misleading as a descriptor for entropy. Entropy is neither disorder nor measure of disorder or chaos. Entropy is not a driving force. Energy's diffusion, dissipation, or dispersion in a final state compared to an initial state is the driving force in chemistry. Entropy is the index of that dispersal within a system and between the system and its surroundings (Lambert 2002a).

Entropy change is a quotient that measures the quantity of the unidirectional flow of thermal energy by $dS \geq dq/T$. This expression could be paraphrased as 'entropy change measures energy's dispersion at a stated temperature'. This energy dispersal is not limited to thermal energy transfer between system and surroundings. It includes redistribution of the same amount of energy in a system (Lambert 2002a).

From a molecular viewpoint, the entropy of s system depends on the number of distinct microscopic quantum states, microstates, that are consistent with the system's macroscopic state. The general statement about entropy in molecular thermodynamics can be 'entropy measures the dispersal of energy among molecules in microstates. An entropy increase in a system involves energy dispersal among more microstates in the system's final state' (Lambert 2002a). With this definitions most of the phenomena such as mixing, expansion of a gas, phase changes in which entropy increase are inadequately described by disorder could be easily explained.

Discussion

The review shows that Entropy is found to be difficult idea to be grasped by high school students and undergraduates. In many cases students' understanding of the basic aspects of the idea are limited, distorted or wrong. The difficulties arise from misinterpretation of mathematical equations in thermodynamics and not adequately integrating the new knowledge with students' existing knowledge. Students' explanations are mostly based on the macrophysical world, their thinking on the microphysical world is limited. The everyday meanings of the scientific terms dominate their interpretations. Lecturers should check that students have acquired the correct scientific meanings of the concepts and apply them in both everyday and theoretical situations.

Physical chemistry instructors may sometimes overestimate students' understandings of the key chemical concepts and underestimate their difficulties in acquiring them. If instructors recognize the possibility of misunderstandings concerning basic concepts and difficulty of learning advanced level concepts on the basis of these misunderstandings they will be better able to teach difficult concepts.

Although there are some studies which reflect the theoretical aspects and students' understandings, there are few systematic research studies. Students' difficulties with entropy need further study as do the other thermodynamic concepts. High school and university students' understanding of the relationships between entropy changes and temperature, entropy and spontaneity, entropy changes in the case of solid and liquid matter would benefit from further research. It is also important to make available the findings of the studies reviewed above into the classroom teachers, lecturers and students. Otherwise, the research studies in science education would not reach the ultimate aim.

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Резюме

КАК СТУДЕНТЫ ПОНИМАЮТ ЭНТРОПИЮ: ОБЗОР ВЫБРАННОЙ ЛИТЕРАТУРЫ

Мустафа Созбилир

Статья посвящена обзору выбранных исследований понимания студентами понятия энтропия. Обзор взаимосвязывает значимые результаты исследований, неправильные трактовки и новые подходы к определению данного понятия. Исследование показывает, что студенты сталкиваеться с трудностями не только в изучении энтропии, но и других термодинамических концепций. Преподователи должны проверить, что студенты приобрели правильные научные понимания /толкования/ концепций и применяют их в разных ситуациях. Проведённое исследование может представлять интерес для учёных и преподавателей, работающих в области естественнонаучного и химического образования.

Ключевые слова: неправильное понимание, энтропия, высшее образование.

Received 15 November 2002; accepted 21 February 2003

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