Turkish Prospective Chemistry Teachers' Misunderstandings of Enthalpy and Spontaneity

Mustafa Sozbilir[†,*] and Judith M Bennett[‡]

[†]*Ataturk University, Kazim Karabekir Education Faculty, Department of Secondary Science and Mathematics Education, 25240-Erzurum/TURKEY and* [‡]*The University of York, Department of Educational Studies, Heslington, York YO10 5DD UK, sozbilir@atauni.edu.tr*

Received March 17, 2005. Accepted July 15, 2006.

Abstract: This study is aimed at identifying and classifying Turkish prospective chemistry teachers' misunderstandings of enthalpy and spontaneity. In order to fulfill this aim, open-ended diagnostic questions and semi-structured interviews were used after the topic was taught. Diagnostic questions were answered by forty-five students who took physical chemistry courses from two different chemistry education departments in two different universities in Turkey. Seven interviews were carried out just after the administration of the tests. Ten different misunderstandings were identified. Although some of the results of this study confirm the previous research findings, it goes beyond them by identifying new misunderstandings and suggests places where these misunderstandings may originate. The results have implications for tertiary-level teaching, suggesting that a substantial review of teaching strategies is needed.

Introduction

Many students, from the secondary level to the university level struggle to learn chemistry and many do not succeed [1]. Research now shows that many students do not correctly understand fundamental concepts [2] and many of the scientifically incorrect ideas held by the students go unchanged from the early years of their schooling, through university, and even to adulthood [3]. By not fully and appropriately understanding fundamental concepts, many students have trouble understanding the more advanced concepts that build upon these fundamental concepts [4].

The constructivist theory of learning suggests that knowledge is constructed through a process of interaction between an outside stimulus and conceptions that already exist in the learner's mind. During the learning process, some existing conceptions are modified and some new ones are created. Different views on the nature of students' understanding and differences in the methodologies employed to discover students' conceptions have led researchers to make differing claims. One of the widely discussed theories of science learning is that children's conceptions are genuinely theory-like, that is, they have a coherent internal structure and are used consistently in different contexts [5]. This notion is articulated by McCloskey [6] and supported by Engel, Clough, and Driver [7]. McCloskey argues that people develop well-articulated naive theories based on their everyday experiences. Furthermore, he argues that these naive theories are consistent across individuals. On the other hand, diSessa [8] raises issues to do with the nature of misunderstandings. diSessa questions the views of McCloskey and argues that people hold loosely connected, fragmented ideas, some of which reinforce each other but none of which have the rigor of theory. In diSessa's words, students have "knowledge in pieces." diSessa goes on to suggest that there is evidence in his work of students making up explanations spontaneously at the point that they are faced with a question, drawing where they can on core intuitions based on everyday experience (These notions were called phenomenological primitives or p-prims). Later work, for example that of Southerland et al. [9] provides additional support for the notion that students make up explanations spontaneously. Students' explanations, therefore, may not be misconceptions, but rather they are spontaneous constructions, which might be scientifically correct or incorrect (*misunderstandings*). In this study, the word "misunderstandings" is preferred to the word "misconceptions." If it is accepted that some students reason from core intuition, a great deal of variability in students' explanations is to be expected [9].

Many high school and university students experience difficulties with fundamental thermodynamic ideas in chemistry [10]. Despite the importance of thermodynamics as a foundation of chemistry, most students emerge from introductory courses with only a very limited understanding of this subject [11]. Enthalpy is one of the fundamental thermodynamic concepts in chemistry and an entirely general concept. It is applicable to every process, chemical reaction or not, and every state of a system at constant pressure. Students learn enthalpy generally in upper-secondary school or at higher levels. In secondary school, students are usually taught the concepts of "heat" and "chemical energy" instead of enthalpy. As it is impossible to define enthalpy qualitatively, we talk about enthalpy change. Enthalpy change is the energy transferred as heat at a constant pressure. Enthalpy change for a specific reaction can be defined as *the heat exchanged with the surroundings in the course of the reaction when the reaction occurs at constant pressure* [12, p 145]. Although students' understanding of the energy concept for a range of ages was extensively studied [13–25], students' ideas and misunderstandings about enthalpy have received relatively little attention from science educators and researchers. There have been a limited number of studies carried out at the upper-secondary [26] and university [4, 10, 27–31] levels. If science teachers are aware of the misunderstandings they will be better

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

Table 1. Examples of Students' Misunderstandings of Enthalpy and Spontaneity Identified Previously

Misunderstandings identified	Reference
Endothermic reactions cannot be spontaneous	4, 26
Viewing enthalpy as a form of energy	34, 30, 31
Incomplete definition of enthalpy change	34
No heat is transferred under isothermal conditions	4
Bond breaking releases energy, conversely bond making requires energy	29, 33
A chemical reaction is spontaneous if we do not need to interfere	1, 28, 35
A chemical reaction is spontaneous if it is observable	35
Spontaneous reactions occur rapidly	28
No activation energy is required in spontaneous reactions	28
Spontaneous reactions occur when heat evolves from the system to the surroundings	28

able to plan teaching activities and prevent new misunderstandings. Thus, this study will be of interest to chemistry teacher trainers, researchers, and chemistry teachers. Some of the misunderstandings identified prior to this study about enthalpy and spontaneity are presented in Table 1.

The First Law of the Thermodynamics, which states that the energy of an isolated system is constant, is taught to high school students in order to apply it in calculations of enthalpy changes in chemical reactions [32, 33]. It is a basic idea that energy is released when bonds form and energy is required to break the bonds. Studies show, however, that students' understanding is often the opposite of this [29, 32].

High school students' ideas about thermodynamic concepts such as enthalpy, entropy, and free energy were addressed by Johnstone et al. [26]. In order to reveal the conceptual difficulties experienced by students, they wrote a thermodynamics approach test that was given to 98 pupils from 10 different schools. The results showed that approximately one pupil in six had the misunderstanding that endothermic reactions cannot be spontaneous. They attributed this to the universal rule that situations tend spontaneously to a lower-energy position. They also noted that this misunderstanding was not new and historically there was a belief held by the famous chemists Berthelot and Thomsen in 1878 that reactions have to be exothermic to be spontaneous. They suggested that this kind of misunderstandings could be overcome by teaching students through small groups. A large lecture class is not the best medium for the presentation of thermodynamic concepts. It was also reported that the same misunderstanding was identified in 75% of the college students who took the physical chemistry course and 60% of them thought that no heat transfer occurs under isothermal conditions [4].

In another study, Carson and Watson [34] studied first-year chemistry undergraduates' understanding of enthalpy change and found that students viewed enthalpy as a form of energy. In addition, none of their sample was able to associate work with chemical reactions and the concept of *PV* work was unknown. Moreover, it was found that 9 out of 16 students were not able to give a precise definition for enthalpy change. Their definitions were restricted to a specific type of reaction, such as neutralization. In the same study, students also were asked about common thermodynamic mathematical expressions, and the study found that many of the students did no more than recognize the names of the symbols. Kaper and Goedhart [30–31] questioned the use of the "forms of energy" notion and concluded that although a consistent use of the word energy in this way at the secondary level is possible in many cases, the use of this notion is inconsistent with thermodynamics and creates obstacles.

Pupils' conception of energy is widely studied [13–25]. Gilbert and Watts [16] gathered those views in three broad groups that "energy is to do with living and moving things," "energy makes things work," and "energy changes from one form to another." These widespread misconceptions gathered by Watts [25] were categorized by Gilbert and Pope [15] as *anthropocentric, depository, ingredient, activity, product, functional, and flow-transfer*. Later, Trumper [21] refined these categories and investigated further with Israeli students at different levels [20–24]. Trumper [24], in his study carried out with prospective biology students, found that those students' understanding of the energy concept was considerably *anthropocentric*, that is, energy is associated with human beings.

Ross [18] identified that many students thought that energy is released when chemical bonds break in contrast to the chemists' view. Ross suggests that these misunderstandings arise due to the association between fuel and energy, and that this is a barrier to learning the concepts. He argues that misuse of terms in everyday life causes students to develop misunderstandings and, therefore, words should be chosen carefully in teaching. Additionally, students should be given more time to reinterpret, use, and apply the new ideas in their science lessons. Barker [32] studied A-level students' ideas about thermodynamics and found that only 1 in 5 beginning A-level students thought that bond breaking releases energy and conversely bond making requires energy. This was similar to the findings of Ross [18]. She attributes this to the fact that fuels are taught to be energy stores.

In order to find out how fourth-year undergraduates in chemistry interpret the chemical phenomena using the words *reaction* and *spontaneous,* Ribeiro et al [35] conducted a clinical interview study with 14 students. The students were shown four experiments related to the topic and then they were asked about the phenomena. The results revealed that the majority of the students used the everyday notion of the word "spontaneous," thus the word "spontaneity" was related to observable features such that *a chemical reaction is spontaneous if it is observable*. The findings also revealed another misunderstanding that *a chemical reaction is spontaneous if we do not need to interfere*. According to them, the main source of these misunderstandings is everyday use of the words. It was stressed that science teachers must pay careful attention to everyday, out-of-class ideas associated with the concepts. Another suggestion was that students should be helped to see clearly the contextual differentiation of their knowledge. The final comment was that students should be given closer guidance when they are trying to apply theoretical knowledge to practical situations. It is argued that conventional lectures and laboratory classes may not be the best vehicles to overcome these misunderstandings.

Selepe and Bradley [28] investigated 56 final-year college student teachers' ideas and areas of conceptual difficulties in thermodynamics. They used questionnaires and interviews. Their research revealed similar misunderstandings as with Ribeiro et al. [35] but also some new ones such as that spontaneous reactions occur rapidly have no activation energy, and spontaneous reactions occur when heat evolves from the system to the surroundings. They also found that the sign of

the change in enthalpy was used as a determinant for spontaneity. They argued that everyday use of the word "spontaneity" which means "immediate action or rapidity" causes misunderstandings in students.

The Purpose of the Study

This study addressed the question "What are Turkish prospective chemistry teachers' misunderstandings of enthalpy and spontaneity?" With respect to the university education in Turkey, prospective chemistry teachers have studied some of the concepts of thermodynamics at a very basic level both prior to university and in general chemistry courses in the first year of their study in the participating departments. All the subjects in the participating departments are trained as chemistry teachers. Chemistry teacher training was a four-year program (eight semesters with two semesters in each year) at the time of this study was carried out, although high school (14–17 years of age) teachers are now subject to complete a five-year program called Master's Degree integrated with Bachelor's Degree since 2003.

Methodology

This study describes part of a longitudinal research project [36]. A diagnostic questionnaire consisting of open-ended questions on key chemical ideas in thermodynamics including five questions on enthalpy and spontaneity was developed and applied as a posttest to forty-five students who took a physical chemistry course from two chemistry teacher-training departments in two different universities in Turkey. Physical Chemistry is introduced in the third year. The course content was similar in both departments. One of the participating universities is situated in western Turkey and the other is situated in eastern Turkey. The administration of the diagnostic questionnaire was carried out by the researcher in a lecture hour (50 minutes). Students were not permitted to take the diagnostic questionnaire out of the classroom or discuss it with their friends or their lecturers.

In this study, it was accepted that a good diagnostic question is one that generates information that accesses a respondent's thinking about the ideas being explored [36, p 331]. The five diagnostic questions that were used in this study tested the following ideas related to enthalpy and spontaneity:

- The enthalpy change of a reaction depends on the overall strengths of the bonds of molecules and/or compounds in the reactants and the products.
- Enthalpy change is the energy transferred as heat at a constant pressure.
- The change in enthalpy can be a guide to stability of products and the reaction stability but gives no indication of the rate of a reaction.
- Both endothermic and exothermic reactions can be spontaneous.
- Enthalpy is an extensive property, which means that the enthalpy of a substance depends on the size of the sample.

Two sample diagnostic questions can be seen in the appendix showing the concepts being tested and the expected answer (for the complete diagnostic test see 36; pp 385–405). The analysis of the students' responses to the diagnostic questions initially consisted of developing a set of misunderstanding statements about enthalpy and spontaneity. Following this, frequencies of the misunderstandings were determined and tabulated.

A number of interviews were carried out just after the test was given in order to support the data obtained from the questionnaires. Seven interviews sought to explore the students' understanding of enthalpy and spontaneity in detail. The interviewees were selected on a voluntary basis and the interviews took place in a staff member's office on a one-to-one basis. Each interview was tape-recorded and then transcribed fully. Students' permission to tape-record the interview was sought in each case. Interview durations varied from half an hour to 45 minutes. Students were not told about the content before the interviews started, but they were aware that it would be in the same vein as the questionnaire. The interviews were not carried out as a freestanding study and so were not subjected to rigorous analysis; however, it is helpful for readers to know that interview data was corroborative and that there were no contradictions with data from the questionnaire. Selected extracts from these interviews are reported here to help highlight and support the evidence found from the questionnaire data.

The content and the design of the courses were determined by the lecturers and the content and the design were similar in both departments. The physical chemistry course is divided into two main sections in the participating departments. Thermodynamics is covered in the fifth semester and kinetics is the subject of the sixth semester. The sections of the thermodynamics course in which entropy is covered include

- The properties of gases
- The First Law of Thermodynamics
- The Second Law of Thermodynamics

Enthalpy, the subject of this study, is covered under the First Law of Thermodynamics towards to the middle of the fifth semester for a five-weeks period (four class hours per week and a total of twenty class hours). The subheadings covered in both departments are work, heat, energy, the First Law, heat and enthalpy, standard enthalpy changes, enthalpies of formation, the temperature dependence of reaction enthalpies, state functions and exact differentials, and work of adiabatic expansion. With respect to the characteristics of teaching, the courses could be defined as exposition-dominated lecturing. That means the lecturer actively presents the content, and short discussions and question/answers sessions take place occasionally. In addition, homework is given to the students. Because there is a lack of quality physical chemistry textbooks written in Turkish, lecturers mostly follow textbooks written in English and students, most of whom do not know English, have to rely on notes they take during lectures. Students do not find this situation easy [37].

Results

An overview of the prospective chemistry teachers' misunderstandings after teaching is given below followed by a detailed examination of some of the students' responses. Table 2 shows the percentages of the misunderstandings identified after teaching. The quotations taken from students' written responses are indicated as (written response-B or -E) and interviews as (interview-B or -E); B and E stand for the institutions where the data was collected, and R and I stand for

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

Table 2. Misunderstandings Identified About Enthalpy and Spontaneity

Misunderstandings Identified	% (n = 45)
1. Exothermic reactions occur faster or endothermic reactions occur faster	35%
2. Endothermic reactions cannot be spontaneous/A spontaneous reaction is always exothermic	32%
3. Dissolution is always exothermic or endothermic	11%
4. The rate of a reaction is only affected by the temperature of the reaction environment	11%
5. Bond making requires energy or bond breaking releases energy	10%
6. Standard enthalpy of formation is always exothermic	6%
7. Misunderstanding heat and temperature	6%
8. Confusing endothermic and exothermic reactions	6%

the researcher and the interviewee respectively in the dialogues taken from interviews.

Exothermic Reactions Occur Faster or Endothermic Reactions Occur Faster. The analysis of the responses showed that a quarter of the respondents (26%) argued that exothermic reactions occur faster.

> The first reaction is an exothermic reaction. There is no need for energy to cause this reaction in contrast to the second reaction. The products release energy and they are more stable because they have less energy. Therefore, the first reaction occurs faster (written response-E).

As seen from the above quotation, the student distinguishes two types of reactions: those that need energy, for activation or otherwise, and those that do not. Those that need energy are called endothermic by the student. In this case combustion would be endothermic, as a burning match is needed to start it. It is clear here that the student confuses activation energy and reaction enthalpy and uses these concepts interchangeably. In addition, the student approaches the question in terms of stability. As energy is given out in exothermic reactions, the products are more stable than the reactants. The student may think that this energy release may increase the reaction rate and therefore exothermic reactions would be faster. This indicates that prospective teachers confused the rate of a reaction with the spontaneous occurrence of a reaction. The amount of energy required or released can indicate the stability of the reaction as well as being a sign of the spontaneous occurrence of a reaction; however it does not provide information about how fast it occurs. The rate of a reaction is the concern of kinetics while enthalpy change is the subject of thermodynamics. In other words, students confuse thermodynamic data and kinetics.

> An exothermic reaction happens more easily and faster. Because it is easier to release energy than to get the energy even if the ambient temperature is the same. Therefore, exothermic reactions occur faster (written response-B).

It seems from the above quotation that the respondent confused "energy" as used in chemistry with "energy" as used in everyday language because the energy we talk about in everyday language is something that always has a cost and an effort is required to get it. In addition, some of the respondents approached the problem from the point of view that less energy means more stability. Because the total energy of the products is less than that of the reactants in exothermic reactions, many students thought that chemical reactions should occur towards the lower energy direction regardless of considering the factors that alter the rate of a reaction. The quotations show that a significant proportion of undergraduates are still unaware of the fact that it is not correct to make an estimation about the kinetics of a chemical reaction by using thermodynamic quantities. Some of these misunderstandings may be due to an inability to differentiate between kinetic and thermodynamic data.

Nine percent of the responses asserted that endothermic reactions occur fast. The responses centered on the idea that the rate of exothermic reactions is conversely affected by the temperature increase, but an increase in temperature positively affects the rate of endothermic reactions. Because the reactions occur at a certain temperature, the required energy is available for endothermic reactions; therefore, they happen faster. The following response illustrates this.

> The colder the ambient temperature the faster the exothermic reactions occur. The hotter the ambient temperature the faster the endothermic reactions occur. Since there is a certain ambient temperature the endothermic reaction should occur faster (written response-E).

This response shows that the respondent confused the ambient temperature and the optimum temperature at which a reaction occurs with a maximum yield; however, both the rate and the yield are determined by one temperature, the ambient temperature, and this ambient temperature is what the respondent is talking about. The respondent seems to confuse reaction rate and yield. For an exothermic reaction the student expects the reaction to go faster at a lower temperature although, in fact, the yield is better, not the rate.

Endothermic Reactions Cannot Be Spontaneous/A Spontaneous Reaction is Always Exothermic. This is also a well-documented misunderstanding from previous studies [4, 36]. Endothermic reactions cannot be spontaneous was identified in 26% of the responses. It is an important fact that endothermic reactions can be spontaneous. There are examples in everyday life such as the vaporization of water at every temperature. This is an endothermic reaction but it occurs spontaneously. It is also important to note that enthalpy is not the only driving force in a chemical reaction; entropy should also be considered because it is the Gibbs energy that determines whether a reaction is spontaneous or not at constant temperature and pressure. The following responses illustrate the misunderstanding:

> This is an endothermic reaction. This reaction cannot occur spontaneously. Therefore, energy should be supplied from the surroundings to help the reaction happen (written response-B).

The interview results also support data from the questionnaire:

> R: Can you tell me does reaction exothermicity and endothermicity have an effect on the spontaneous occurrence of a reaction?
>
> I: If a reaction occurs spontaneously it gives out energy. I mean it is an exothermic reaction.
>
> R: OK

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

I: Endothermic reactions need energy. Therefore, they cannot occur spontaneously (interview-B).

This misunderstanding was also observed by Johnstone et al. [26] in high school students. According to that research, one in six pupils had this misunderstanding. Thomas and Schwenz [4] also reported that 75% of the fourth-year chemistry undergraduates had this misunderstanding, which may originate from the notion that in spontaneous changes there is a tendency to minimize the energy [26]. As endothermic reactions are accompanied by an energy intake, students may consider that there is an energy increase and thus this cannot be spontaneous. In addition, students have generally been given an exothermic reaction as an example in their courses, because spontaneous endothermic reactions are rare, which may be another possible cause of the misunderstanding.

There was a different formulation of the same misunderstanding that a spontaneous reaction is always exothermic, which was found in 6% of the responses. Some quotations given below exemplify this error:

This reaction can occur spontaneously, therefore it releases energy… (written response-B).

The reaction happens spontaneously, thus it gives out energy (written response-B).

This is an exothermic reaction. Exothermic reactions occur spontaneously. If a reaction occurs spontaneously it gives out heat. Therefore, there is an energy release after the reaction (written response-B).

In the third response, the respondent explores the fact that exothermic reactions occur spontaneously. This is true, but the reverse is not always true as some endothermic reactions proceed spontaneously as explained above for the misunderstanding that endothermic reactions cannot be spontaneous. Prospective teachers are most likely to formulate this misunderstanding from the perspective that if an exothermic reaction occurs spontaneously, conversely all the spontaneous reactions should be exothermic.

Spontaneity was approached from an energy point of view and none of the prospective teachers mentioned that an entropy change occurs in the universe as a result of a chemical reaction. They argued that, because endothermic reactions require energy to occur, they cannot be spontaneous. This approach might be due to the consideration of one aspect of spontaneity. In fact, enthalpy is the one important component of the Gibbs energy change that helps to determine the tendency for spontaneous occurrence of a reaction at constant T and P; however, prospective teachers failed to consider entropy, which is the other important component. This misunderstanding might stem from a lack of knowledge about what spontaneity is, as Ribeiro et al [35] reported. In their study undergraduates argued that a chemical reaction is spontaneous if we do not need to interfere or if it is observable. This view can be seen in the responses below.

...the second reaction requires heat to occur. There is a need for energy. I mean it only can occur with an outside interference (written response-B).

As they [endothermic reactions] require heat, endothermic reactions cannot be spontaneous (written response-E).

There are two approaches, one from the energy viewpoint and the other from a spontaneity point of view. The respondents thought that, if energy is needed from outside to stimulate the reaction, it cannot be spontaneous. In order to be a spontaneous reaction, there should be no interference to the reaction system from outside of the system.

Dissolution is always Exothermic or Endothermic. This misunderstanding was identified in 11% of responses. The respondents argued that dissolution of the solid is always exothermic or endothermic. It is not possible to make this generalization as dissolution of some salts is endothermic such as KNO_3 or NH_4NO_3. However, when some salts, such as $CaCl_2$ and $CuSO_4$, dissolve they generate energy and the process is exothermic. Students made a generalization by relying on only one case as shown below:

...Because the dissolving process is always endothermic (written response-B).

The dissolution of the solid is always exothermic (written response-B).

$CuSO_4$ is a salt. All salts give out heat when they dissolve in water (written response-E).

This misunderstanding might be the result of considering the dissolving process as consisting of breaking of intramolecular bonds, which requires energy from the water. This would lead to the misunderstanding that *the dissolution process is always endothermic*. Subsequently, the ions are hydrated by the individual water molecules, and this process is exothermic, leading to the misunderstanding that *the dissolution process is always exothermic*.

Rate of a Reaction is Only Affected by the Temperature of the Reaction Environment. Almost one in ten respondents displayed this particular misunderstanding. It was argued that, as shown below, the rate of a reaction only depends on the temperature.

The rates of chemical reactions depend only on the temperature... (written response-B).

The only factor which affects the rate of a reaction is temperature... (written response-E).

These respondents may have misunderstood the fact that the rate constant of a reaction changes with temperature instead of the rate of a reaction or they just did not know the difference between them.

Bond Making Requires Energy or Bond Breaking Releases Energy. This is a well-known misunderstanding from studies on students' understanding of chemical bonding [18; 29; 32]. Barker [32] reports that 19% of A-level students hold this misunderstanding. The misunderstanding was observed in 10% of the responses. It is of considerable note that this misunderstanding is still persistent at this level of undergraduate education. Some typical quotations from the responses are given below:

Chemical bonds are broken and form during a chemical reaction. Bond breaking releases energy, and bond making requires energy... (written response-E).

The energy given out when the bond between H-H breaks and the bonds in O_2 molecules break is bigger than the energy required for the formation of H_2O molecules... (written response-B).

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

> In this reaction since the bonds are broken in H_2 and O_2 molecules, some energy is given out... (written response-E).

> In this reaction, it is easier to break the bonds in H_2 and O_2 therefore they give out more energy than the energy has taken to form H_2O... (written response-B).

Interview data also supports the questionnaire data. The following dialogue was taken from an interview:

> R: Would you tell me have you ever thought that why some reactions are exothermic while some of them are endothermic? Where might this difference arise, or what might it be?

> I: Some reactions involve bond formation and some involve bond breaking. Bond formation requires energy. If a bond breaks it releases energy.

> R: You think that bond breaking releases energy, and bond making requires energy?

> I: Yes...

> R: How do you know that?

> I: We learned this (interview-E).

This misunderstanding might be due to the strong association between fuels and energy, which Ross [18] believes prevent learning the accepted chemists' view. Students believe that molecules are the energy store, and when the bonds are broken and molecules are destroyed, this energy is released. This view is similar to pupils' view of energy as *depository* articulated by Gilbert and Pope [15]. Ross [20] and Barker [32–33] attribute students' difficulties to the way that fuels are described as energy stores during teaching. In addition, Boo [29] argues that a large number of students see the chemical bond as a physical entity and students link the everyday notion that building any structure requires energy input and its converse destruction releases energy. This kind of thinking may form the basis for the misunderstanding that bond breaking releases energy and bond making requires energy.

Standard Enthalpy of Formation Is Always Exothermic. This particular misunderstanding was observed in the responses given to the question provided in the appendix and was included in 6% of the responses. It is assumed that students concluded this from the exothermic reaction given as an example because it is a formation reaction of water; however, the second reaction was also a formation reaction but students did not state the same misunderstanding there. Some typical responses are quoted below:

> When two or more atoms are gathered together to form a molecule, heat is generated. This heat is formation enthalpy at the same time... (written response-B).

> ...the formation enthalpy of elements is zero.Here in this reaction the heat that comes out actually belongs to the formation of water. Formation enthalpies are always exothermic... (written response-B).

Students clearly stated this misunderstanding, which may originate from the fact that most of the formation reactions are exothermic and the number of endothermic formation reactions is relatively low compared to exothermic formation reactions. This misunderstanding may also stem from students' habits of handling the question only in the available circumstances instead of handling it in a wider perspective.

Misunderstanding Heat and Temperature. A small percentage of the responses showed some misunderstandings about heat and temperature. One of the respondents confused the sign of the energy transferred as heat with temperature by stating that

> ...the temperature is negative in exothermic reactions and it is positive in endothermic reactions... (written response-E).

The negative and positive signs show the energy released or energy required by a reaction, not the temperature of the system. In addition, some of the students made statements like

> The rates of these reactions depend on the ambient temperature and the temperature required or released in the reactions (written response-E).

It is clear that this respondent does not distinguish between temperature and heat. Although few respondents showed this misunderstanding in their written responses, it was observed with a much higher frequency in the interviews. Heat was also confused with the definition of a "calorie" in some cases.

> R: You have just mentioned heat energy haven't you? Could you tell me what you mean by heat energy?

> I: ...(pause) It is the amount of energy that it should be given to increase the temperature of a certain amount of water by 1°C.

> R: So could you tell me, what is the difference between heat and temperature?

> I: Heat is energy. Temperature...(long silence) I can't make a proper definition but heat exists due to temperature. I mean heat occurs because of temperature. There is a heating but,.. I can't explain. I have something in my mind but,...

> R: Can you give an example of what you have in your mind?

> I: Emm,... for example, emm.. if we put some water on a fire its temperature increases and we give it heat energy proportional to the temperature (interview-B).

The interviewee defined heat as a calorie as well as considering that heat is the result of temperature change. This might be due to the conventional definition that heat is the energy that flows from hot to cold objects. The following discussion also shows that undergraduates misunderstood the above definition of heat.

> R: Could you tell me what you know about enthalpy?

> I: Enthalpy reminds me of heat. In an endothermic reaction heat is supplied, if the reaction is exothermic heat is released then.

> R: OK, so what is the heat then?

> I: Heat is the way of flow of the temperature from one object to another.

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

R: Could you repeat what you said in the last sentence for me please, I couldn't get exactly what you mean?

I: Yes, I mean, it is the way of exchange of temperature between two objects.

R: So, in this case how would you define the temperature?

I: Temperature is the energy exchange between two objects.

R: Can you give me an example what kind of energy exchange you mean?

I: For instance, if we put together two objects when they are at different temperatures, there will be a heat transfer until their temperatures are equal. In thermal equilibrium their temperatures are the same. I mean, the temperature is this energy that is exchanged (interview-E).

The interviewee had no clear understanding of heat and temperature and demonstrated a common misunderstanding that is well known and well documented in the literature. Studies such as that of Brook et al. [38, 39] show similar findings. In their study, 15-year-olds thought that "heat and temperature are the same." In this study undergraduates did not state this directly but their answers denote that they still use the terms "temperature" and "heat" interchangeably.

Confusing Endothermic and Exothermic Reactions. This final misunderstanding was only diagnosed in 6% of responses. Respondents gave statements like:

An exothermic reaction is a reaction that requires energy to occur, and an endothermic reaction is a reaction that releases energy when it occurs... (written response-E).

Anecdotal evidence suggests that this confusion is common amongst secondary-level Turkish pupils, because the foreign words "exothermic" and "endothermic" are used in the textbooks and also by their teachers. Students need to memorize these terms and subsequently find it difficult to differentiate between them and use them correctly. This is mostly a language-related misunderstanding, which rarely persists throughout the undergraduate level.

Discussion and Conclusion

Enthalpy is a fundamental concept in chemistry. The responses suggest that it is poorly understood by prospective chemistry teachers despite the fact that they are taught it several times at different stages of their education. The source of the energy in a chemical reaction appears problematic for prospective teachers from several points of view. Prospective teachers perceived the energy associated with a chemical reaction rather differently than a chemist. These results are in good agreement with Trumper's [24] study, which shows that prospective teachers have difficulties with the energy concept as applied in many process; however, there is no evidence to suggest that Turkish prospective chemistry teachers have the *anthropocentric* view of energy as was the case with Israeli biology students. In addition, as in the case of the common misunderstanding that *bond breaking releases energy and bond making requires energy*, it appears that prospective teachers have a *depository* view of energy. The responses showed that they generally consider the energy in exothermic and endothermic reactions as different, because in many cases they give unlike reasons for the energy released or required by the reactions. It seems that they have the notion that the energy in an endothermic reaction on the reactants side is only the activation energy and that exothermic reactions do not need activation energy. The prospective teachers reasoned that the energy in an endothermic reaction would be used to start the reaction. This view of energy appears to be similar to what Trumper [21] calls the "cause framework." They also thought that the source of the energy in exothermic reactions was different from that of endothermic reactions. A small number of prospective teachers mentioned that the energy released or required in a chemical reaction depends only on the total strength of the chemical bonds that are broken and formed before and after reaction. In addition, many prospective teachers still confused whether the energy is required or the energy is released in a chemical reaction. This is, perhaps, due to considering the molecules or compounds as energy sources. If we destroy them, they release energy and conversely when they form, they store energy. This result again supports Trumper [21]. Alternatively, it may originate from extrapolating views about events in the macroscopic world into the microscopic world—in the macroscopic world, energy is needed to make things; therefore, in the microscopic world, energy is also needed to make bonds [29].

The responses revealed that some of the prospective teachers still hold the same familiar misunderstandings, such as endothermic reactions cannot be spontaneous, spontaneous reactions occur rapidly, and bond making requires energy and bond breaking releases energy. They also revealed new misunderstandings such as *the rate of a reaction is only affected by the temperature of the reaction environment; dissolution is always exothermic or endothermic and all enthalpies of formation are exothermic*.

As a result, prospective teachers' understanding of enthalpy is poor even at a very basic level. Prospective teachers are able to memorize the facts but cannot apply them to the problems they come across. In addition, prospective teachers' knowledge is fragmented. They have snippets of knowledge about enthalpy change and dissolution but are not able to apply this knowledge. This result supports the arguments made by diSessa [8]. This could be the result of rather formal teacher-centered teaching. These chunks of knowledge require a very low use of intellectual or cognitive skills [40]; therefore, prospective teachers should be taught using a more student-centered learning approach so that they can get the help they need to establish the links between the different ideas.

Implications for Teaching

The results of this study suggest that many prospective teachers have difficulties in understanding enthalpy as well as difficulties in understanding advanced thermodynamics and kinetics concepts [36]. It is likely that many of the difficulties identified in this study might be found among physical chemistry students in general, although the subjects in this study were from only two chemistry education departments in Turkey. The findings of the present study may provide some clues about the quality of student learning in typical physical chemistry classes. The results indicate that a substantial review of teaching strategies at the tertiary education level is essential.

Because this study provides evidence that prospective teachers' explanations of scientific phenomena are based on the macro physical world and that they have a very limited

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

ability to think at the molecular level, instructors should try to assure that prospective teachers understand the correct scientific meaning of enthalpy and related concepts and that they can apply that meaning in different situations, whether it is an everyday phenomenon or a theoretical one [28]. In addition, university instructors should pay attention to the everyday, out-of-the-classroom ideas associated with the scientific terms they use. They should also assure that undergraduates understand those concepts in the way they intend them to be understood. As it has been previously argued [35], the best way to become aware of the shortcomings in one's own knowledge is to match it against that of others. A classroom discussion covering areas of confusion could be an effective way of identifying students' learning difficulties and stimulating the students to think about the basic concepts needed to solve a problem before proceeding to a solution. Short-answer questions prepared in different forms, such as multiple choice, true/false, and two-tier diagnostic questions could be an alternative in determining students' misunderstandings both prior to teaching and during teaching. Furthermore, in-class writing, previously used [41] to identify students' learning difficulties in thermodynamics, could be another alternative. The essence of in-class writing is based on posing short-answer open-ended questions to students during teaching. Reading in-class writing of students may provide clues to the level of students' understandings and the misunderstandings they hold during the teaching process. A previous study [41] provides evidence that in-class writing is a powerful means for identifying students' problems and misunderstandings so that they can be remedied at the time. Showing good student writing to the students during the next lecture can help clarify troublesome concepts. In addition, a lecturer can go on to give additional coverage in the identified topics if necessary. Still, this should happen in non-threatening manner. Perhaps employing an informal and ungraded format would be a better way to probe student knowledge effectively.

It was argued that a context-based approach, using scientific applications and context as a starting point in teaching, may provide better help for students in developing an understanding of some areas of chemistry as compared to traditional approaches [42]. A recent study [43] provides evidence that the context-based approach for teaching chemical thermodynamics at the undergraduate level improves learning as well as increases interest in chemistry. It is believed that the context-based approach can be a viable alternative to the more traditional approach without sacrificing rigor or quality of learning. In addition, another study [34] points out that thermodynamic entities are defined qualitatively and their effects talked about before they are defined quantitatively; therefore, it is suggested that there is a need to reverse the usual procedure where numerical problem solutions are set first and then understanding follows. Holman and Pilling's [43] study applied this notion in teaching chemical thermodynamics and reported success in the quality of student learning. As a result, it could be suggested that the content of and nature of physical chemistry courses might be reconsidered by escaping it from a textbook-and-derivation-driven course and providing informative and interesting content-rich materials to help students learn. Some of the mathematical burden can be removed by the appropriate use of software to enable students to focus on learning the significance of physical chemistry [37]. Moreover, as suggested by Zielinski and Schwenz [44] optimal use of information technology and computer resources, such as visualizations, simulations, and animations, should be encouraged and students should be provided these resources.

Finally studies, which reflect the theoretical aspects and students' understanding of enthalpy are, limited [45]. Students' difficulties with enthalpy need further exploration, as do misunderstandings with other thermodynamic concepts. High school and university students' understanding of the relationships between enthalpy changes, spontaneity, and entropy would benefit from further research. It is also important to make available the findings of the studies reviewed above to classroom teachers, lecturers, and students so that their findings may be incorporated into practice.

Acknowledgement. We thank the students and the lecturers who took part in this research and acknowledge financial support from Ataturk University. We would also like to acknowledge the reviewers of this manuscript for many thoughtful comments and suggestions.

Appendix. Two Sample Diagnostic Questions Used in the Test.

Energy

$$H_{2(g)} + \tfrac{1}{2}\, O_{2(g)} \rightarrow H_2O_{(g)} \qquad \Delta_f H^0 = -\,242 \text{ kJ mol}^{-1} \quad \text{(a)}$$

This thermochemical equation tells us that 242 kJ of energy are released as heat at constant pressure when 1 mol H_2 molecules reacts with ½ mol O_2 to form 1 mol H_2O.

Explain as carefully as you can why energy is released in this reaction.

$$N_{2(g)} + 2\, O_{2(g)} \rightarrow 2\, NO_{2(g)} \quad \Delta_r H^0 = 68 \text{ kJ mol}^{-1} \quad \text{(b)}$$

This thermochemical equation tells us that energy is required at constant pressure when 1 mol N_2 reacts with 2 mol O_2 to form 2 mol NO_2.

Explain as carefully as you can why energy is required in this reaction.

The idea being tested: The enthalpy change of a reaction depends on the overall strengths of the bonds of molecules and/or compounds of the reactants and the products.

The expected answer: For both sub-questions the answer is the same. The energy given out or gained in a reaction depends on the overall strengths of the bonds of molecules and/or compounds of the reactants and the products. If the overall strengths of the bonds are more than those of the products then energy is required to perform the reaction and it is called as an endothermic reaction. Alternatively if the situation is reversed it would be called an exothermic reaction. In other words, if weaker bonds are broken and stronger bonds are made then the system supplies energy as heat to the surroundings and such reactions are called exothermic. Conversely if stronger bonds are broken and weaker bonds are made the surroundings supply heat to the system and such reactions are called endothermic [12; p 162].

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf

Two Hypothetical Reactions

The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1

$$A + B \leftrightarrows C + D \qquad \text{Exothermic}$$

Reaction 2

$$E + F \leftrightarrows G + H \qquad \text{Endothermic}$$

(a) On the basis of this information, can you compare the rate of these two reactions? If so, how? Explain your answer as carefully as you can.

(b) What do you think about the spontaneity of these two reactions? Explain your answer as carefully as you can.

The ideas being tested:

(a) The change in enthalpy can be a guide to stability of products and the reaction stability but gives no indication of the rate of a reaction.

(b) Both endothermic and exothermic reactions can be spontaneous.

The expected answers:

(a) Thermodynamics quantities say nothing about the rate of a reaction; hence, it is not possible to compare the rate of the reactions according to reaction enthalpy.

(b) Both of these hypothetical reactions (exothermic and endothermic) can be spontaneous.

References and Notes

1. Nakhleh M.B. *J. Chem. Educ.* **1992,** *69* (3), 191–196.
2. Griffiths A. K., A critical analysis and synthesis of research on students' chemistry misconceptions. In *Problem Solving and Misconceptions in Chemistry and Physics;* Schmidt, H. J., Ed. Proceedings of the 1994 International Seminar, University of Dortmund, Germany, 1994, pp 70–99.
3. Gil-Perez, D.; Carrascosa, J. *Sci. Educ.* **1990,** *74* (5), 531–540.
4. Thomas, P.L.; Schwenz, R.W. *J. Res. Sci. Teach.* **1998,** *35* (10), 1151–1160.
5. Driver, R. *Int. J. Sci. Educ*, **1989,** *11* (Special Issue), 481–490.
6. McCloskey, M. Naive theories of motion. In *Mental Models;* Gentner, G.; Stevens, A. L., Eds. Lawrence Erlbaum: New Jersey, 1983; pp 299–324.
7. Engel Clough, E.; Driver, R. *Sci. Educ.* **1986,** *70* (4), 473–496.
8. diSessa, A. A. Knowledge in pieces. In *Constructivism in the Computer Age;* Forman, G.; Pufall, P., Eds. Lawrence Erlbaum: New Jersey, 1988; pp 49–70.
9. Southerland, S.A.; Abrams, E., Cummins, C.L.; Anzelmo, J. *Sci. Educ*. **2001,** *85,* 328–348.
10. Banerjee, A.C. *J. Chem. Educ.* **1995,** *72* (10), 879–881.
11. Ochs, R.S. *J. Chem. Educ.* **1996,** *73* (10), 952–954.
12. Maple, J. Advanced Chemistry: An enquiry-based approach, John Murray Press, London, UK, 1996.
13. Barak, J.; Gorodetsky, M.; Chipman, D. *Int.J. Sci. Educ.* **1997,** *19* (1), 21–30.
14. Duit, R. *Eu. J. Sci. Educ.* **1987,** *9,* 139–145.
15. Gilbert, J; Pope, M. *Res. Sci. Tech. Educ.* **1986,** *4,* 61–76.
16. Gilbert, J; Watts, D. *Stud. Sci. Educ.* **1983,** *10,* 61–98.
17. Nicholls, G.; Ogborn, J. *Int.J. Sci. Educ.* **1993,** *15,* 73–81.
18. Ross, K. A. *School Science Review* **1993,** *75* (271), 39–47.
19. Solomon, J. Phys. Educ. **1985,** 20, 165–170.
20. Trumper, R. *Phys. Educ.* **1990a,** *25,* 208–212.
21. Trumper, R. *Int. J. Sci. Educ.* **1990b,** *12,* 343–354.
22. Trumper, R. *Int. J. Sci. Educ.* **1991,** *13* (1), 1–10.
23. Trumper, R. *Int. J. Sci. Educ.* **1993,** *15,* 139–148.
24. Trumper, R. *Int. J. Sci. Educ.* **1997,** *19* (1), 31–46.
25. Watts, D. M. *Phys. Educ.* **1983,** *18,* 213–217.
26. Johnstone, A. H.; MacDonald, J. J.; Webb, G. *Phys. Educ.* **1977,** *May,* 248–251.
27. Carson, E. M.; Watson, J.R. *University Chem. Educ.* **2002,** *6,* 4–12.
28. Selepe, C.; Bradley, J. Student-Teacher's Conceptual Difficulties in Chemical Thermodynamics. In *SAARMSE Fifth Annual Meeting;* Sanders, M., Ed. University of the Witwatersrand: Johannesburg, South Africa, 1997; pp 316–321.
29. Boo, H. K. *J. Res. Sci. Teach.* **1998,** *35* (5), 569–581.
30. Kaper, W. H.; Goedhart, M.J. *Int.J. Sci. Educ.* **2002a,** *24* (1), 81–95.
31. Kaper, W. H.; Goedhart, M.J. *Int.J. Sci. Educ.* **2002b,** *24* (2), 119–137.
32. Barker, V. Ph.D. Thesis. University of York, York, UK, 1995.
33. Barker, V.; Millar, R., *Int.J. Sci. Educ.* **2000,** *22* (11), 1171–1200.
34. Carson, E. M.; Watson, J.R. *University Chem. Educ.* **1999,** *3,* 46–51.
35. Ribeiro, M. G. T. C.; Periera, D. J. V. C.; Maskill, R. *Int.J. Sci. Educ.* **1990,** *12,* 391–401.
36. Sozbilir, M. PhD Thesis. University of York, York, UK, 2001.
37. Sozbilir, M. *J. Chem. Educ.* **2004,** *81* (4), 573–578.
38. Brook, A.; Briggs, H.; Bell, B.; Driver, R. Aspects of secondary students' understanding of heat: Full Report. *Children's Learning in Science Project*. Centre for Studies Science and Mathematics Education: University of Leeds, Leeds, UK, 1984.
39. Brook, A.; Briggs, H.; Bell, B.; Driver, R. Secondary students' ideas about heat: Full Report. *Children's Learning in Science Project;* Centre for Studies Science and Mathematics Education, University of Leeds: Leeds, UK, 1985. This seems to be a variation of reference 38.
40. Hudson, T. Developing pupils' skills. In Levinson, R., Ed. *Teaching Science;* Routledge: London, UK. 1995; pp 94–109.
41. Beall, H. *J. Chem. Educ.* **1994,** *71* (12), 1056–1057.
42. Ramsden, J.M. *Int.J. Sci. Educ.* **1997**, *19* (6), 697–710.
43. Holman, J.; Pilling, G. *J. Chem. Educ.* **2004**, *81* (3), 373–375.
44. Zielinski, T.Z.; Schwenz, R.W. *Chem. Educ.* **2004,** *9* (2), 108–121.
45. Sozbilir, M. *J. Baltic Sci. Educ.* **2003,** *3* (1), 21–27.

© 2006 *The Chemical Educator*, S1430-4171(06)1072-0, Published on Web 10/1/2006, 10.1333/s00897061072a, 11050355ms.pdf