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Research Article

Difficulties in Learning the Concept of Internal Energy

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Abstract: This study analyzes students' main difficulties in learning the concept of internal energy and related concepts. To carry out this analysis we have supposed that the historical study of the main qualitative leaps that have taken place in the construction of the theory of internal energy may help to diagnose such difficulties. Thus, we have made a brief description of the main conceptual profiles with in which internal energy can be interpreted by Ethiopian and examined to what extent they are used by students in two public universities. To achieve this we have devised and applied an open-ended questionnaire and interviews. The results obtained showed that most students, in the two universities, have ontological and epistemological difficulties using the idea of internal energy thus preferring the use of reasoning based on the chemical thermodynamics concepts in chemistry.

Keywords: Conceptual understanding, internal energy, learning difficulties

INTRODUCTION

Students are often told that chemistry is "the study of matter and the changes that it undergoes" (Chang and Goldsby, 2012). What is not as often emphasized is that understanding chemistry also depends upon an understanding of the central role of energy in chemical systems. From the structure of individual atoms to the folding of complex bio-molecules, from the simplest reactions to the cascades of coupled reactions that have enabled living systems to remain organized and fight the tendency to disorder, understanding energy and energy changes are key According to Ethiopian higher education Harmonized curriculum for BSC degree program in chemistry (MOE, 2009) this central role is learnt in physical chemistry courses, where students tackle more advanced concepts of thermodynamics and kinetics, are perceived by many students to be their most difficult courses (Thomas, 1997).

Furthermore, there is evidence that even university-level students may have foundational learning difficulty about the nature of heat and energy. For instance, some students view energy as substance or material quantity (Duit, 1987) or as a driving force or causal agent in a chemical reaction (Thomas and Schwenz, 1998).

At the heart of challenges surrounding heat and work may be the fact that the terms such as "energy" or "heat" and that the language used to discuss them often contains implicit metaphors comparing heat and work to quantities that can be found in everyday life (Jin and Anderson, 2012; Kaper and Goedhart, 2002; Lancor, 2012). In transitioning to discussions of energy in science contexts, students must come to appreciate energy as an abstraction and as a tool for reasoning, which may be in conflict with everyday language. Clearly these findings are problematic; the use of mathematical resources to model and represent systems is a key scientific practice that has the potential to facilitate students' understanding of energy transfer and conservation in more complex systems. However, if an appreciation of the concepts underlying thermodynamic functions does not exist, it becomes nearly impossible for students to appreciate energy as a tool for reasoning which they may then use in appropriate ways to explain and predict the outcomes of chemical processes.

Generally a thermodynamic treatment of energy and energy changes does not build on students' prior knowledge (for example from physics), but rather introduces a new set of concepts that may appear to the student to be introduced solely for the purpose of doing calculations. It is necessary for them to transfer a conceptual rather than an algorithmic understanding to these subjects.

Energy concepts are critical to understanding how molecules form and behave. These are generally introduced during discussions of the structure and interactions of matter. These ideas may be taught introduced either before or after thermo chemistry, but are required to make sense of thermo chemistry. Only at the atomic-molecular level can the interactions responsible for the observable manifestations of energy changes be observed.

Bonding and intermolecular interactions are foundational parts of chemistry in that they enable

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predictions of molecular properties at the macroscopic level. It is possible to explain most of the properties and interactions of matter, from the sizes of atoms to their interactions along the spectrum, from London Dispersion Forces to covalent bonding, in terms of kinetic and potential energy. To understand bonding at a conceptual level in terms of energy, students must recognize that such interactions are based on attractive and repulsive forces and that a stable interaction is formed when there is a balance between these forces, 'energy minimum' (Nahum *et al*., 2007). Developing such an understanding, however, may be challenging for students. Since covalent bonds, ionic bonds and intermolecular forces are often treated as different entities; many students consider bonds as distinct from intermolecular forces, despite the fact that both are types of electrostatic interactions (Taber, 1998). In reasoning about bond formation and stability, students may rely on heuristics such as the octet rule, rather than an understanding of how electrostatic forces contribute to the minimization of potential energy through bond formation (Taber, 1998). Similarly, the topic of bond energies is also a source of difficulty-even after instruction typically over 50% of students believes that bonds release energy when they are broken (Barker and Millar, 2000; Boo, 1998). Most students bring with them prior knowledge that is more likely to anchored in the macroscopic level and may have great difficulty in translating macroscopic concepts to the atomic molecular level. For instance, the construct of potential energy is most often introduced in reference to gravitational potential energy in secondary school course work. It has been noted that students may struggle with understandings of gravitational potential energy. For instance, Loverude (2005) noted that undergraduate non-science majors enrolled in an introductory physics had difficulty in describing variables upon which gravitational energy depends and that many students used definitions of potential energy in which they seemed to believe that potential energy meant the 'potential' for movement. It seems plausible that students might have similar difficulties in interpreting potential energy in other contexts, including chemistry.

In introductory chemistry courses, potential energy is often referenced when discussing intermolecular forces and bonding but rarely is the relationship between potential energy at the molecular level and gravitational potential energy elaborated. While electrostatic potential energy can be considered somewhat analogous to gravitational potential energy in that both depend on an object's position within a field, electrostatic potential energy is more complex since there are two types of charges and therefore both attractive and repulsive forces, in contrast to the solely attractive force active in a gravitational field. Students may be left to interrelationships between macroscopic and molecular ideas for themselves.

In studies of high school and university-level students' explanations of electrostatic phenomena it has been found that despite instruction, students tend not to use energy and field-based explanations and instead appeal to explanations that deal with the interaction of charge, or the movement of charged particles when explaining observations of properties related to electrostatic interactions and potential energy (Furio and Guisasola, 1998; Shen and Linn, 2011). This finding may be understandable if one considers the abstract nature of electrostatic fields; reasoning about electrostatics requires students to reason about particulate-level objects (like electrons) and abstraction such as field and potential energy (Chabay and Sherwood, 2006).

For example: In studies (Sam, 2007) of what students understand by the term 'potential energy', we find that almost uniformly, from beginning level students to upper level chemistry majors and graduate students tend to fall back on their first introduction to the term to explain it. Their depictions of potential energy include 'balls rolling down hills' and are almost always concerned with gravitational potential energy, rather than molecular level explanations. There is almost no mention of fields, or the concept that a system of objects must be defined to understand these concepts. Similarly, in march 31st, 2009 report prepared for natural resource Canada a preliminary assessment of renewable energy work related to students' understanding of potential energy, when explicitly asked about potential energy as it refers to chemical systems, they find the undergraduate students are unable to articulate a coherent response, despite the fact that the terms 'potential energy' and 'potential energy minimization' are central to a wide swath of chemistry concepts.

We suggest that students must understand the origin of potential and kinetic energy changes at the atomic-molecular level before they can understand bases of thermodynamic ideas that are in common use. If students do not know how energy is transferred and stored at the atomic molecular level, it is likely they will struggle to understand (for example) the origin of 'chemical energy' how or why chemical reactions can be used as a source of energy (from food to batteries). We must do more to reinforce appropriate interpretations of energy as related to these forces at both macroscopic and atomic-molecular scales and to help students translate ideas of energy across scales.

This research first identify and classify the main difficulties encountered by undergraduates chemistry students in learning thermodynamics concepts in physical chemistry with its source and finally, a possible way to tackle these difficulties with an alternate approach, illustrated by the physical chemistry course in which Structure, Properties and Energy are presented as three interconnected learning progressions was described.

Purpose of the study: The purpose of this study was to determine the basic concept learning difficulty related to internal energy in physical chemistry and to suggest possible implication to tackle these difficulties with an alternative approach illustrated by the introductory physical chemistry courses in which structure, properties and energy are presented as there interconnected learning progression was described for understanding of concepts in thermodynamics for students studying chemistry in Ethiopia universities.

To enhance this aim the following sub-questions were investigated:

- What is the basic concept learning difficulties related to internal Energy?
- What is the implication of concept learning difficulties identified in teaching learning chemical thermodynamics?

METHODOLOGY

Participants: The present study employed a descriptive approach in order to achieve the aim described above. Data was collected from eight-seven undergraduate students. All of them were enrolled to Dire-Dawa and Haramaya University, Ethiopia to Bachelors Degree in Chemistry during 2011-2012 academic years.

Instruments: Two different instruments were used to collect data In order to determine undergraduate student's conceptions in determining internal energy concept a diagnostic test composed of five open-ended questions was specifically developed to test undergraduate student's knowledge of internal Energy.

The researchers' previous experiences in teaching helped them to identify the undergraduates' difficulties in internal Energy. In order to maintain the content validity of the test, it was given to four lecturers who were asked to assess the content, ideas tested and the wording of the questions. All questions were piloted with third year undergraduates taking physical chemistry course. Undergraduates' views about the content and wording of the questions were taken immediately after they completed the test and required modifications were made prior to the administration of the test.

The test was administered under normal class conditions without previous warming two months prior to end of the year. Respondents were given a normal class period of 50 min to complete the test. Students were informed that the results of the test would be used for research purposes and would be kept confidential.

Based on the initial coding of the responses, prevalent conceptual difficulties were identified. These conceptual difficulties articulated how these undergraduate students differentiate the concepts of Energy, but did not provide in dept explanations of their personal views. To address this limitation, thirteen undergraduate students were interviewed in order to clarify their written responses and to further probe conceptual understandings of the questions asked in the test. Interviewees were selected on the basis of their responses on the written test. If a student's written test response demonstrated conceptual learning difficulties without providing an in-depth or clear explanation of his or her response, we requested interviews with them. The interviews lasted approximately 20-30 min. All the interviews were audio recorded (with the interviewees' consent) and then transcribed for analysis. The interviews did not go into great detail; instead they were used to elucidate the students' conceptual learning difficulties based on their written responses.

Data analysis: Students' responses to the diagnostic questions were analyzed, conceptual learning difficulties were determined and percentages were calculated for the responses. Conceptual learning difficulties held by over 25% of the subjects are reported here. Interview data were not subjected to a rigorous analysis but rather was used to support the diagnostic test results.

RESULTS

Analysis of the responses about internal energy and related concepts: The responses to five questions about internal energy and related concepts, Potential Energy, Helium and Carbon Dioxide, Perfect Gas, Explosion in a Steel Box and Water, are analyzed and discussed. The analysis has been done using the qualitative method. Each question is discussed separately and main sections titled with the specific name of the questions used in the questionnaire. In the following section the results of Learning difficulties related to internal energy are summarized as follows:

- Internal energy of perfect gases decreases if the volume increases/pressure decreases in isothermal conditions.
- Internal energy of perfect gases increases/decreases by W (expansion work) in the case of isothermal expansion.
- Internal energy of perfect gases increases if the number of collision of the particles increases in isothermal conditions.

These learning difficulties appear to be related to the students' lack of knowledge of potential energy and kinetic energy of perfect gases because they were identified in the responses given to the question Perfect Gases which examines the students' understanding of internal energy change of perfect gases under isothermal expansion. The concepts that internal energy is the sum of the kinetic energy of all particles and potential energy arising from their interactions with one another was tested. Since the students did not understand potential and kinetic energy properly, as a result they developed the above learning difficulties relating to internal energy. It also appears that learning difficulties may have originated from the misinterpretation of the equation:

$$U = q + W$$

Students thought that at constant temperatures heat change is equal to zero; hence internal energy should only change as a result of work. Students also failed to differentiate the perfect gas and real gas cases.

Another learning difficulty which related to the internal energy was:

- Internal energy of an isolated system increases if a chemical change occurs inside the system.

This learning difficulty showed that students did not consider the whole system but only the changes which occur inside the system such as temperature or pressure increase as a result of a chemical change. Vanessa (2004) pointed out that most thermodynamic problems are multi-variable and students consider them as a series of changes and therefore consider first one of the variables and then another instead of dealing with them as a whole. This type of reasoning was described as linear casual reasoning by Vanessa (2004).

Another group of learning difficulties which related to the change of internal energy was:

- Internal energy of a system does not change by doing work on the system.
- Internal energy only changes with q (heat) given to the system.
- Internal energy change is only equal to the work done on the system.
- Heating a system causes more change in internal energy than doing work on the system.

These learning difficulties show the students' difficulties about essential elements of internal energy which are heat and work. Students confused between heat and work. The majority of the students argued that energy transfer as heat is the major source of the internal energy chance. This may be due to the fact that) argue. Energy transfer as heat causes an apparent change in a system in many more cases than work does, as Erickson and Tiberghien (1985).

Implications for teaching: The results of this study suggest that many students in an advanced undergraduate class have difficulties in acquiring some the most basic chemical concepts as well as having difficulties in acquiring advanced thermodynamic concepts. Conversations with colleagues at other institutions of higher education suggest that it is likely that many of these learning difficulties identified in this study would be found among physical chemistry students in general, although the students in this study were from only two chemistry departments in Ethiopia. Therefore, the findings of the present study may provide some clues about the quality of student learning in typical Chemical thermodynamics classes.

Constructivist theories of knowledge are based on a fundamental assumption that knowledge is constructed in the mind of the learner (Driver, 1989). This suggests that students construct their own meaning by assessing and assimilating the new knowledge to that which they already have. Therefore students' previous knowledge plays a vital role in learning. Chemical thermodynamics lecturers sometimes overestimate their students' understanding of basic concepts. If lecturers recognize the possibility of learning difficulties or no understanding concerning fundamental concepts, they will be better able to organize the teaching and learning environment by addressing and attempting to overcome student learning difficulties (Thomas, 1997). As Ribelro (1992) points out, university lecturers would provide better teaching if they begin with the question 'what do students see, do and know?' Discussion of students' concepts amongst themselves and with lecturers may bring out what they already know and do not know and may provide a way forward for better teaching. Beall (1994) argues that informal in-class writing also provides clues to students' previous knowledge. Overestimating students' previous knowledge and misunderstandings makes the difficulties even more chronic.

In order to improve the students' understanding of important thermodynamic concepts lecturers might concentrate more on the quality than the quantity of material covered during the course, as Thomas (1997) points out. In doing this, some of the students may need extensive help to change their way of thinking about fundamental concepts and replace incorrect beliefs with the scientific ones. Otherwise, if student learning difficulties are not addressed by the lecturers, students might continue to hold them even if they successfully complete the requirements of the course. In addition, as Pushkin (1998) argues, exposure to many concepts at a time promotes memorizing and enhances algorithmic skills instead of conceptual learning.

Since this study provides evidence that students' explanations of scientific phenomena are based on the macro physical world and they have a very limited level of microscopic level thinking, lecturers should check that students have acquired the correct scientific meanings of concepts taught and that they can apply the concepts learned in different situations, whether it is an everyday phenomenon or theoretical one (Selepe and Bradley, 1997). In addition, university lecturers should pay attention to everyday, out-of-class concepts associated with the scientific terms they use. They should also be checking if students have understood in the way they intend Ribelro (1992). As Ribelro (1992) argue the best way of becoming aware of the shortcomings of one's own knowledge is to rub it up against that of others. Discussions with students may provide a better chance of knowing their shortcomings.

In order to overcome the difficulties of confusion among concepts, students might be helped to see clearly the contextual differentiation of their knowledge. This is a major source of student's difficulties. It was argued by Ramsden (1992) 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. In addition, as Carson and Watson (1999) point out, it is important 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. The results of this study support Carson and Watson (1999) findings that students were not able to draw out the meaning attached to the thermodynamic entities defined quantitatively, therefore teaching thermodynamics requires new perspectives rather than traditional teaching methods. It is evident from the literature that traditional teaching methods are ineffective in tackling the students' learning difficulty (Bodner, 1991).

CONCLUSION

In summary chemical thermodynamics course coverage is fragmented, not connected to students earlier Knowledge and typically not set in a meaning full context. The three core energy concepts the macroscopic, which involve thermodynamics and mathematical treatments, the molecular, which describes the origins of energy changes in terms of bonds and the quantum mechanical, which provides the basis for understanding of periodic trends, bonding and interactions of matter and electromagnetic radiation are not well connected and there is often no attempt to make an explicit connection between them most assessment for chemical thermodynamics courses still emphasize rote problem solving and factual recall rather than understanding and there is little opportunity for students to synthesize and connect the internal energy concepts. There is ample evidence that students lack of a coherent framework of internal energy concepts on which they can hang their understanding of internal energy changes associated with chemical change in fact many of the leading text books introduce these topics indifferent orders, so it is clear that there is no consensus on how to develop and connect internal energy concepts or even why it is important.

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