International Journal of Education Sciences (IJES)
Received on 01/23. 06. 2014
REF. NO. IJES-482
(Always refer our Reference No. for all correspondence)
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KEYWORDS Gibbs energy, difficulties in learning, diagnostic test, Chemical thermodynamics

ABSTRACT This article analyzes students' main difficulties in learning the concept of Gibbs 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 Gibbs energy may help to diagnose such difficulties. Thus, we have made a brief description of the main conceptual profiles within which Gibbs 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 question questionnaire and interviews. The results obtained showed that most students, in the two universities, have ontological and epistemological difficulties using the idea of Gibbs energy thus preferring the use of reasoning based on the chemical thermodynamics concepts in chemistry.

1. INTRODUCTION

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 P.L. 1997)From a macroscopic perspective, observable energy changes can be measured and calculated as a result of temperature changes. Although temperature change is a physical manifestation of the energy changes that take place on the atomic-molecular level, most University- level instructional approaches do little to emphasize these origins: they do not explicitly connect the macroscopic (temperature) to the microscopic and molecular.

Instead energy topics are introduced under the general heading of “Thermo chemistry” and later on more generally “Thermodynamics”. Thermo chemistry is concerned with the energy changes that take place when a chemical system undergoes change, and for most students this topic will involve calculations using specific heats and temperatures. Subsequently thermodynamic functions such as enthalpy (H), entropy (S) and Gibbs energy (G) are introduced. However, it is common to find that instruction and assessment are focused on rote calculations of these functions rather than an understanding of the meaning of these thermodynamic functions and how changes in state functions are linked to changes at the Molecular level there is evidence that students approach mathematical representations of thermodynamic functions, such as enthalpy or entropy, in antilogarithmic fashion and that even advanced chemistry students can fail to grasp what these mathematical representations of thermodynamic functions represent. Hadfield and Wieman (2010) found that students enrolled in an upper-division physical chemistry course struggled to interpret the expression U = q + W as related to energy conservation. Similarly, Granville (1985) found that students believed that $\Delta S < 0$ for spontaneous (that is, thermodynamically favorable) processes, suggesting that students did not interpret results in alignment with the Second Law of Thermodynamics. This is troubling given that Gibbs energy is one of the most important and useful thermodynamic functions for many scientists, yet its meaning is poorly understood.

For example, biologists use it to determine the direction of change in biological systems and to understand how coupled reactions can drive thermodynamically unfavorable processes (that is, changes that alone lead to a decrease in total entropy or a positive Gibbs energy change) Yet, there is little evidence that students understand that the change in Gibbs energy is a proxy for the Second Law of thermodynamics Such difficulties may reflect a lack of an accurate underlying understanding of exactly what specific thermodynamic variables represent, For instance, Thomas and Schwenz (1998) found that students enrolled in a university-level physical chemistry course viewed the change in Gibbs energy (ΔG) as related to the amount of heat transferred in or out of a system. Sozbilir (2002) noted that students believed that the magnitude of (ΔG) determined the rate of a reaction while Carson and Waston (2002) observed that students often view entropy as a form of energy. 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 orcausal agent in a chemical reaction (Thomas & 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 & Anderson, 2012; Kaper & 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 languag. 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 such as Gibbs energy 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.

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

Many students from secondary schools to universities in many countries, struggle to learn chemistry and many do not succeed (Reid, 2008). Research has now shown that many students do not correctly understand fundamental chemistry concepts (Haglund and Jeppsson, 2012). And also many of the scientifically incorrect concepts held by the students go unchanged from the early years of the schooling to university and sometimes beyond (Sozbilir, Pyanarbaby, and Nurtac (2010). 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).

In Ethiopia studies have shown that a significant basic chemical concepts and reaction misconceptions were found by both teachers and students in primary and secondary schools (Abayneh, 2013,2012; Sileshi ,2011; Temechegn,2002,Temechegn and Sileshi,2005) .However, little or no work has been done in the country on thermodynamics.

Many high school and university students experience difficulties with fundamental thermodynamic concepts in chemistry (Carson and Watson, 2002). Despite the importance of thermodynamics in the foundation of chemistry, most students emerge from introductory courses with very limited understanding of the subject (Ochs, 1996). The physical chemistry course, where students tackle more advanced concepts of thermodynamics and kinetics, is perceived by many students to be one of the most difficult courses (Thomas, 1997). It has been suggested by sozibiler (2001) that many of the conceptual difficulties in thermodynamics could have an historical basis.

Thermodynamics is fundamental to physical science and the concept of energy and the distinction between intensive and extensive properties contribute to many domains in physical science (Linn and Songer 1991). Thermodynamics is the key to chemistry, physics and all natural sciences. Therefore, if we grasp its essence then we will be able to understand the concepts and principles and apply them in our daily lives, for example; conservation of energy in our houses, maintenance of body temperature, cooking with microwave etc., and we also can realize human behavior in terms of being free and rich (Nordholm 1997). Thermodynamics is a fundamental subject in the university level courses especially in engineering also in chemistry and physics. Thus, it is important to probe students' understanding capabilities in physical chemistry and their problems with grasping and applying the principles of thermodynamics to their everyday lives in terms of the development of industry and standards of human life. Perhaps the most important point is that the students who are the subject of this study will be chemistry teachers when they graduate. Their understanding of the fundamental thermodynamic ideas is crucial in terms of educating tomorrow's generations.

Thermodynamics was chosen for this study for two reasons. Experience of teachers and the literature have shown that thermodynamics is a difficult topic for students to understand. When students are asked to solve numerical problems they have the option of solving the problem by using some algebraic methods, however, most of them are unaware of the understanding behind the problems.

The above study is similar to the findings of the study by Sozbiler(2002), An examination of studies on students' learning of basic physical and chemical concepts clearly demonstrates that most of the basic concepts were poorly learned (Sozbilir and Bennette 2007). Students' learning of fundamental concepts associated with chemical thermodynamics has not yet been the subject of educational research, especially at a more advanced level beyond the general chemistry (Thomas 1997). Relatively little research has been conducted at the tertiary level on students' understandings of entropy and Gibbs energy (Carson and Watson 2002). More research needs to be done to identify what sort of difficulties students face in the learning of physical and chemical concepts. Learning difficulties are important for both teaching and learning. Both science educators and cognitive researchers agree that efforts to understand and improve science education should be focused on fundamentally important knowledge domains (Cheng, 2006). Hence, it has been concluded that it is worthwhile to conduct a research study about chemistry undergraduates' learning difficulties of fundamental thermodynamic function Gibbs concepts, which are a part of the physical chemistry course and the factor which may give rise to these learning difficulties

1.1 Purpose of the Study

The purpose of this study was to determine the basic concept learning difficulty related to Gibbs 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

1. What is the basic concept learning difficulties related to Gibbs Energy?
2. What is the implication of concept learning difficulties identified in teaching learning chemical thermodynamics?

2. Methodolgy

2.1 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.

2.2. 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 eight open-ended questions was specifically developed to test undergraduate student's knowledge of Gibbs Energy

The researchers' previous experiences in teaching helped them to identify the undergraduates' difficulties in Gibbs 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 minutes 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 Gibbs 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 minutes. 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.

2.3 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.

3. RESULT

Analysis of the Responses about learning difficulties about Gibbs energy and related concepts

Many undergraduates who took part in the research were unwilling to answer the questions which related to Gibbs energy because of their lack of knowledge of the concepts. Also the interviews which supported the questionnaire data demonstrated that students have little or no understanding of Gibbs energy. The most common learning difficulties were the confusion of thermodynamics data and kinetics data. Students were more likely to use thermodynamics data to make estimation about the kinetics of a chemical reaction. The essence of the Gibbs energy was also missing. Students were only able to repeat the few facts that they had memorized but failed to apply them to problems which required understanding.

some learning difficulty were identified in less than 5% of the responses. These are:

- *Gibbs energy is zero at equilibrium*
- *Gibbs energy is the energy that is required to start a reaction*
- $\Delta G = - T \Delta H$
- *Entropy only changes with temperature*
- *Gibbs energy increases in a spontaneous reaction.*
- *The slower the reaction, the smaller change in Gibbs energy.*
- *The bigger the Gibbs energy change, the faster a reaction occurs.*
- *The smaller* ΔG*, the faster the reaction occurs.*
- *The bigger* ΔG*, the faster the reaction occurs.*
- *The reaction with bigger Goes towards full completion.*

ΔG

• *If a reaction occurs fast, it goes towards full completion.*

The students' ability to apply of conceptual understandings to problems requiring diagrammatic representations was found to be very low. In a question called *Gibbs Energy* eight different types of incorrect drawings were detected. Overall, it can be said that students' understanding of Gibbs energy is vague due to the lack of encouragement for conceptual understanding and lack of prerequisite knowledge in order to understand the Gibbs energy concept

4. Discussion

Gibbs Energy reflected the students' understanding of the Gibbs energy change accompanying a reaction, as well as the students' ability to present their conceptual understandings by drawing diagrams. The findings showed that only a few of the drawings were correct in the pre-test, but no explanation was provided, therefore the drawings may have been just a lucky guess. In the post- test, one in four students drew the correct graph and provided a correct explanation. However there were some incorrect drawings as shown above. In a study conducted by Sozibiler (2001), in response to a similar question undergraduates mostly drew the graph (d). It was argued that Gibbs energy increases or decreases linearly to make the reaction spontaneous in either direction A $\rightarrow$ B or B $\leftarrow$ A, depending on whether A (reactant) or B (product) had more Gibbs energy to start with . This incorrect concept may originate from the fact that equilibrium is reached at the lowest Gibbs energy position as Sozibiler argued. The fact that Gibbs energy change tends to become zero when the system approaches equilibrium and becomes zero at equilibrium had not registered in the undergraduates' mind. A few respondents stated that Gibbs energy becomes zero at equilibrium indicating that students' confused Gibbs energy change and Gibbs energy itself because Gibbs energy change becomes zero at the equilibrium state.

5. Conclusions

This manuscript provides evidence of poor or no understanding of Gibbs energy amongst undergraduates. The key findings can be summarized as follows. The questions testing the concepts related to Gibbs energy were not popular ones as the blank response rate ranged between 30% and 80%. It was also apparent that a large number of students who responded to the questions demonstrated no understanding. The significant learning difficulties were related to using thermodynamic data to estimate the changes in the kinetics of a reaction. Undergraduates failed to differentiate between the kinetics and thermodynamics of a chemical reaction perhaps due to an incorrect application of a physical sense into chemical thermodynamics.

Some undergraduates' learning difficulties seemed to originate from the incorrect application of everyday experiences the chemical events. Some learning difficulties were also connected with the related concepts. Misunderstandings about Gibbs energy seemed to originate from no understanding of, or perhaps not knowing, related ideas such as equilibrium and reaction dynamic. Some also seemed to have originated from the students' lack of mathematical knowledge since physical chemistry lessons often involve a lot of complicated mathematical problems. A solution to this problem would be to teach the concept using less mathematics and to put more effort into teaching for conceptual understandings.

With respect to solving problems by using drawing skills and presenting the results as diagrams, undergraduates demonstrated a poor understanding and lack of capability. A high number of respondents (80%) left the question called *Gibbs Energy* blank in the pre-test. The students' drawings demonstrated a limited understanding of the concept and also displayed learning difficulties and confusions. Moreover, the results suggested that students were quite likely to develop new learning difficulties after teaching, indicating that Gibbs energy was a difficult concept to grasp.

The pre and post-interviews revealed some new learning difficulties about Gibbs energy which were not identified through the questionnaire. In the pre-interviews, students were only asked what they knew about Gibbs energy and why it is known as free energy. Students' responses showed either very little or no understanding of Gibbs energy. The only fact many students remembered was that Gibbs energy helps to estimate whether a chemical reaction occurs or not as illustrated below:

R: Could you tell me what do you know about Gibbs energy?

I: ...emm... it helps us to estimate whether a reaction happens or not. Enthalpy and entropy are used in calculation of Gibbs energy. There is an equation.
ΔG # $=\Delta H$#- $T\Delta S$#. In this equation if $\Delta G < 0$, I think the reaction happens, if $\Delta G < 0$ it does not happen. If $G = 0$ it is in equilibrium (student from Dire -dawa university)

A few of the interviewees demonstrated an understanding of what free energy means. However in general, they were not able to explain why Gibbs energy is known as free energy. The responses were mainly composed of guesses and showed little scientific explanation as shown below:

R: Gibbs energy is called as free energy as you know. Could you tell me why it was called as free energy? Where may it come from?

I: It is a kind of energy when molecules are stable, they don't move, or it has in it when it is free... (Students from dire-dawa university)

In another interview, one of the interviewees responded to the same question as follows:
I: free [long silence] it may be energy of substances when they are free *(students from haromaya university).*

The interviewees' responses reflect the everyday meaning of word 'free' unlike what meant by free energy in chemistry.

The post-interviews demonstrated some previously unidentified learning difficulties about Gibbs energy. Learning difficulties centered on the spontaneity and Gibbs energy, and reaction rate and the magnitude of Gibbs energy change. Students' understandings of spontaneity of a reaction were limited as they argued that if there is no external interference in the reaction it is spontaneous. Scientifically a spontaneous process is one which has a tendency to occur as determined by a negative Gibbs energy change (Sozibiler,2001). Students' understanding of spontaneous shows parallels with meanings used in everyday language as Ochs (1996) argues. This can be seen from the following dialogue:

R: What do you mean by spontaneous?

I: Without an external influence, if the conditions are available a reaction can happen without an external help, it happens spontaneously

R: Can you give me an example? I: Yes, rusting, rusting of iron...
R: Could you tell me how can you understand whether a chemical reaction occurs spontaneously or not? Is there a criterion? If yes, what is the criterion?

I: Of course there is, reaction heat reaction enthalpy. At constant temperature, I mean in a spontaneous reaction, reaction enthalpy should be smaller than zero.

R: Do you mean the reaction should be exothermic?

I: ... emm... exothermic, endothermic in fact it is not conditional at the end. Enthalpy should be considered but we know like this (Students from Haramaya University).

The interviewee's understanding of spontaneity is not consistent with the scientific one. In many similar responses students repeated the everyday meaning of spontaneous. It is also clear from the dialogue that the interviewee did not understand the criterion for a spontaneous reaction which is a widespread learning difficulty amongst the undergraduates. They perceive enthalpy as a criterion for spontaneity of a reaction instead of Gibbs energy. Similar findings were also revealed by Lancor (2012). Ochs (1996) argues that the word spontaneous, as used in the context of chemical thermodynamics, is inconsistent, and often misleading. It is commonly used without definition and its meaning varies amongst authors using it. The dictionary definitions do not fit the strict chemical definition of a negative change in Gibbs energy. Undergraduates did not understand the difference between thermodynamic data and kinetic data and often used thermodynamic data to estimate kinetics changes in a chemical reaction. Teachers and lectures need to be careful in distinguishing between kinetics and thermodynamics.

6. 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 thermodynamics 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 Ribeiro (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. Cochran and Heron (2006) argue 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 (Lancor, 2012). 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 Ribeiro (1992). As Ribeiro *et al* (1990) 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 Bucy (2007) 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 (2002) 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's (2002) 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 Christen,Meltzer and Ogilivie(2009).

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 energy concepts .there is ample evidence that students lack of a coherent framework of energy concepts on which they can hang their understanding of 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 energy concepts or even why it is important as a result this thesis develop an intervention strategy to tackle some of the learning difficulties

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