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CONCEPTUAL DIFFICULTIES ABOUT SOME CHEMICAL THERMODYNAMICS CONCEPTS AMONG STUDENT-TEACHERS AND LECTURERS AT COLLEGES OF EDUCATION

Mamoraka Caroline Selepe

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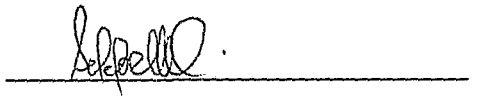
Mamoraka Caroline Selepe

A research report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science.

Johannesburg 1997

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



M. C. SELEPE

18 day of December, 1997

ABSTRACT

The purpose of this research was to identify and describe ideas held and conceptual difficulties experienced by third year Secondary Teacher's Diploma students and lecturers at colleges of education. The thermodynamics concepts investigated were the basic ones of temperature, heat and energy and the more advanced ones of entropy, spontaneity and free energy. Data was collected by means of pre- and post-questionnaires and interviews. Fifty six student-teachers and eight college lecturers completed pre-questionnaires. Forty eight student-teachers and eight college lecturers completed the post-questionnaire. Ten student-teachers were interviewed after completing the post-questionnaire. The questionnaires and interviews revealed a number of erroneous ideas and difficult learning areas with both the basic and advanced concepts As regards the basic concepts, the views of the student-teachers were similar to those of school children's views reported by researchers in other countries. They also showed conceptual difficulties in areas such as the criteria used to determine if a chemical reaction had occurred or not, whether the reaction was spontaneous or not, the role of entropy in chemical processes, the relationship between entropy and disorder, factors affecting entropy and the role of free energy in chemical reactions. Both questionnaires showed that some of the lecturers have misconceptions similar to those of students. This in part at least explains why the STD 3 students learning is not successful. Nine students from a university academic development programme also completed the post-questionnaire. They showed a much better understanding of the concepts investigated. The conceptual difficulties identified in this research challenge the teaching methodologies used at colleges of education to teach thermodynamics meaningfully. College of education lecturers need to be supported by well designed inservice training programmes in the teaching of thermodynamics. Development of a teacher resource package that will among others address the conceptual difficulties identified here is recommended.

DEDICATION

Dedicated to my parents. Mamogudi and Shoabute, who encouraged and inspired me to appreciate education, my sons, Shoabute and Molebogeng, my sisters and brother.

ACKNOWLEDGEMENTS

The completion of this study would not have been successful without many people. My sincere gratitude goes to my supervisor Prof J.D. Bradley for his patience and dedication in guiding me through the process of compiling this report. His constructive criticism of my drafts helped me to gradually develop as a science educator researcher and to understand and realise the challenges facing researchers in science education.

I also wish to thank colleges of education lecturers and students of Elijah Mango, Modjadji, Mokopane, Sekhukhuni and Setotolwane Colleges of Education and College of Science students (University of the Witwatersrand) who took part in this study.

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I thank God for giving me strength, dedication and perseverance until the end of this study.

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CHAPTER 1

INTRODUCTION: BACKGROUND AND SIGNIFICANCE OF THE PROBLEM

1.1 Background

Scientists and science educators would agree that the efforts to understand and improve science education should focus on fundamentally important knowledge domains and look into the problems that affect understanding of the fundamental concepts. A better conceptual understanding of the fundamental concepts will obviously lead to a better understanding of more complex concepts.

In the last decade there has been extensive research into student's understanding of scientific concepts across the science areas. In Physics an indepth research has been done in a broad range of important topics. Interest in student's and teacher's misunderstandings and conceptual difficulties in Chemistry has also increased (Griffiths and Preston, 1992; Garnett and Treagust, 1992). In Chemistry, student's misconceptions and learning difficulties have been reported in chemical reactions (Anderson, 1986; Schollum , 1982; Ben-Zvi, et al, 1987; Ribeiro et al, 1990; Abraham et al, 1992; Long, 1993), chemical equilibrium (Bradley et al, 1990; Banerjee, 1991; Johnstone et al, 1977a; Wheeler and Kass, 1978), particulate nature of matter (Novick and Nussbaum, 1981), mole concept (Duncan and Johnstone, 1979), electrochemistry (Ogude, 1991; Garnett and Treagust, 1992). Very few studies were reported (Johnstone et al, 1977b; Lowe, 1988; Granville, 1985; Ben-Zvi et al, 1990; Ribeiro, 1992) which identified student's understanding of chemical thermodynamics.

Most of the research in science education has tried to answer questions about the nature of student's misconceptions, the source of these misconceptions and the effect instruction has on student misconceptions. These questions have only been partially answered (Abraham et al, 1992). In the dawn of these studies, misconceptions were mainly identified with young children at elementary schools. Their ideas about the nature of scientific

concepts were called non-scientific ideas, alternative conceptions, intuitive ideas or children's science (Doran, 1972; Gilbert and Watts, 1983; Driver et al, 1985; Ogude, 1991). These descriptions were generally applied to conceptions held before instruction and even after instruction. There has been a great debate about the correct usage of these terms among researchers, but a consensus reached was to use preconceptions, misconceptions and alternative frameworks (Ogude, 1991; Nussbaum and Novick, 1982; Hewson and Hewson, 1983). In this study the terms "alternative ideas" and "misconceptions" will be used equivalently, except where the questions relate to a concept before instruction, when "preconceptions" will be used.

It is well documented that a prevalence of misconceptions has got serious implications on learning and teaching. Misconceptions normally go undetected during traditional teaching, and hence they can be transferred from one class to another and from one topic to another. The most serious implications are the hindrance of cognitive understanding of new concepts. A learner is able to complete his studies without being aware of the wrong scientific conceptions he is holding. This is very detrimental to teaching if the learner intends following a career in teaching. The shortcomings of the traditional teaching methods are well known to foster misconceptions, which are very difficult to eliminate.

Lately, misconceptions have been identified to be prevalent among high school pupils, university students and even among teachers world- wide. In South Africa misconceptions studies have been conducted in the various areas of Chemistry and educational institutions as mentioned before by researchers such as Helm (1978), Hewson and Hewson (1983) and Bradley and coworkers (1984-1993). In all these studies, nothing has been done so far in Chemical Thermodynamics. Chemical equilibrium and chemical reactions are fundamentally linked with chemical thermodynamics. Hence the extensive reports on chemical equilibria and chemical reactions misconceptions suggest that students and experienced science teachers must be having conceptual difficulties with chemical thermodynamics.

1.2 The problem

> "In recent years there has been frequent and wide spread commendation of starting to teach thermodynamics at stages

> earlier than the traditional starting points (first year courses at English universities and the second year course in Scottish universities). The teaching of thermodynamics in schools is a topic which [illegible] vokes strongly held points of view. Although the [illegible] has continued for over a decade, no end appears to be at hand." (Wright, 1974)

It is true that the introduction of chemical thermodynamics at institutions below universities creates a considerable controversy among academics and probably the curriculum developers (personal experience). The major problem could be that thermodynamics is too difficult to learn due to its abstractness. Most teachers at schools are not well qualified to teach thermodynamics, partly due to "scandalous" inaccuracy of the thermodynamics teaching at a number of universities (Wright,1974).

On the contrary Ogborn (1974) and Johnstone et al, (1977b) defend its position at institutions lower than the universities. Subsequent research done by some researchers mentioned previously and in the next chapter indicates that it is feasible to teach thermodynamics at these institutions. The success of this lies in the identification of misconceptions in the basic concepts such as heat, temperature and energy and the advanced concepts of enthalpy, free energy and entropy.

In South Africa, there has been a recent change in science curricula at colleges of education writing the Department of Education and Training Examinations. The new curriculum for the Secondary Teachers Diploma includes a more advanced treatment on chemical thermodynamics, which is similar to that of a first year (English) university programme in Chemistry. A survey of research literature indicated that this topic is associated with teaching and learning problems. Lots of misunderstandings in the basic thermodynamics concepts such as heat, temperature and energy have been identified (See literature review). It is in the light of these previous researches that the introduction of concepts such as entropy, free energy and spontaneity at colleges of education could be expected to be associated with learning problems.

1.3 Significance of the problem

Thermodynamics, as its name implies, is concerned with a simultaneous study of the heat and other energy changes which a system could undergo. Understanding thermodynamics is significant to us in the sense that we are able to understand the world around us. With the applications of thermodynamics, life becomes very easy. In the homes conservation of energy in the cooling and heating systems, cooking with microwaves and operating refrigerators relies on the role played by thermodynamics. The scientists use thermodynamics to correlate and predict the behaviour of real systems containing matter. In industry, for example, engineering scientists deal with the practical uses of thermodynamics. Their abilities to interconvert heat and work, separate components from solutions and to obtain optimum yields from chemical reactions is dependent on a thorough knowledge of thermodynamics. In biological systems, thermodynamics controls the maintenance of body temperature.

In the classroom, thermodynamics is concerned with the simultaneous study of heat and other energy changes which a chemical or physical system can undergo. It provides integration and connection of concepts in chemistry and physics, and thus contributes a lot towards understanding of natural phenomena.

Understanding thermodynamics depends upon an understanding or conceptualization of energy, work, enthalpy, entropy and free energy. At high school students learn about various aspects of chemical ener y: exothermic and endothermic reactions, enthalpies, heat and temperature. It is just unfortunate that the curriculum at this level presents these concepts as separate entities. The result of such a compartmentalization may be conceptual difficulties among teachers and students. This may have led researchers such as Wright (1974) to argue and claim that thermodynamics should not be taught at schools because of its inherent difficulties. Other researchers such as Johnstone et al (1977b) and Ogborn (1974) argued that thermodynamics should be taught at schools. The aim should be to study thermodynamics in ways that bring about the links between all concepts related to thermodynamics.

It seems then that in order for learners to understand the laws of thermodynamics, and their application to systems, they should be familiar with the basic concepts such as energy and

temperature and also be able to differentiate between them. It can then be argued that understanding of advanced concepts such as entropy and free energy, and the laws that determine change would be easier if these fundamental concepts are learned.

Thermodynamics is a multivariate discipline. This means that thermodynamics deal simultaneously with many variables: for example, changes in energy, temperature, system and surroundings may be incorporated in one problem or situation. A student is forced to deal simultaneously with all the variables. In thermodynamics and other related topics, most variables may entail mathematical calculations. Students tend to manipulate mathematical formulae mechanically without understanding the concepts underlying it (Ogborn, 1974; Johnstone et al, 1977b; Granville, 1985; Cohen, 1987; Ribeiro et al, 1990; Ogude, 1991). In most of the exam papers it has been found that students did badly in questions which require conceptual understanding. Students who obtained good grades in science courses have been reported to have done badly in problems that require qualitative explanations but well in mathematical calculations (Ogude, 1991). Parsons (1989) also noted this problem in his study on chemical equation balancing with standard 8 pupils.

Colleges of education in South Africa are a key component in the education sector. Many schools are fed by teachers emanating from colleges of education. A lot of these teachers teach science up to matric level. It is important that student-teachers learn and understand science concepts well while still at the college. This is to make sure that misconceptions are not transferred to pupils as these student-teachers enter the teaching arena.

The purpose of the study is to identify some of the difficulties lecturers and student-teachers encounter in teaching and learning chemical thermodynamics concepts. Their conceptions are identified before and after instruction in the new college curricula.

The analysis of data in this research is mainly qualitative, with the major objective of characterising students's explanations of the concepts under investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

> "Thermodynamics is one of the amazing disciplines in science. Its two laws contain the complete basis for establishing the states of pure and mixed systems and their tendencies for change." (O'Connell, 1993).

It has been well documented that students and well educated people regard thermodynamics as a very difficult and abstract discipline to teach and learn. In this chapter, a review of literature relating the difficulties and problems associated with chemical thermodynamics is outlined. Most of the articles covering this subject reveal school children's and university student's misconceptions. Relevant research articles about thermodynamics misconceptions among student-teachers and science teachers are not available. Related concepts such as chemical equilibria, under which misunderstandings about thermodynamics have been identified, are also reviewed.

2.2 Heat, temperature and energy

The concepts of heat and temperature are well known for presenting students with conceptual difficulties. Intensive research about heat, temperature and chemical energy conceptions has been undertaken by a number of researchers (Summers, 1983; Brook, et al, 1984; Cohen, 1987; Erickson, 1979; Ben-Zvi, et al, 1990; Erickson, 1980; Erickson and Tiberghien, 1985; Linn and Songer, 1991; Kesidou and Duit, 1993; Lewis and Linn, 1994; Thomaz et al, 1995). These researchers reported various misconceptions. For example, heat is often used as a noun in everyday language as though it signifies something that a substance can contain. This usually causes confusion between the meaning of heat and internal energy.

There also exist great difficulties in the distinction between heat and temperature. Many students can not distinguish between heat and temperature. For example, Cohen (1987) reported that her Israeli students gave statements such as:

- "measure your heat".....meaning body temperature.
- "Temperature transfer".....meaning heat energy transfer.

Probably this confusion is fostered by the meaning attributed to these words in the everyday language, which differs from scientific meanings.

> *" The word 'heat' and its literal and metaphorical derivatives are commonly used as nouns, verbs, adjectives and adverbs. It is the use as a noun, which creates most of the conceptual confusion from the scientific and more specifically from an energy point of view. For example we frequently hear expressions such as 'close the window and keep the heat in' or 'keep the cold out'. In classrooms we may hear pupils saying that heat is gained or lost by an object when it comes into thermal equilibrium with some other substance, or that heat ' travels along a metal rod ' when the metal rod is heated by a flame at one end."*
>
> (Erickson and Tiberghien in Driver, et al (eds), 1985).

Driver and Russell (1982) and Engel (1981; in Brook et al, 1984) also reported children's confusion and the use of temperature and heat as synonyms.

Scientists consider temperature as a physical quantity that describes the state of a system. Knowledge of temperature is essential in predicting the changes which will occur in one system when it interacts with another system. It is a macroscopic property which expresses the state of disordered motion of particles. It is related to the kinetic energy of these particles. Temperature describes the average kinetic energy of the molecules of a substance. The higher the average kinetic energy, the higher the temperature. When a substance is heated, the average kinetic energy of its molecules is increased and the temperature of that substance increases.

The molecules which make up a substance have both kinetic energy and potential energy. The sum of these two, for all the molecules of which the substance is composed, is called the internal energy of that substance. The internal energy of a substance is dependent on the temperature of that substance. One mole of water molecules at 20°C has less internal energy than one mole of water molecules at 45°C. At any one temperature, the average kinetic energy of the molecules of all substances is the same, but the distribution of these kinetic

energies between the rotational, vibrational and translational energy differs.

Heat is a term that describes interactions between systems. It refers to a process of energy transfer. It is the difference of temperatures between two systems which determines whether or not heat transfer will occur. Heating is one of the processes by which thermal energy is transferred from one object to another. Therefore heat is referred to in many science textbooks as a form of energy, which is confusing and probably fosters misconceptions. It is better to use "thermal energy" instead of "heat" for the type of energy transferred, and heating for the process of transferring thermal energy. This will help in differentiating between everyday language and the scientific meaning of 'heat'.

Heating a substance increases the internal energy of the substance. This increase in internal energy will be seen as either an increase in temperature of the substance (an increase in average kinetic energy of the particles of the substance), or a change in phase of the substance (an increase in the potential energy of the particles of the substance).

Scientists view thermal equilibrium thus: When a hot object is brought into contact with a cold object, thermal energy is transferred from the hot object to the cold object, until the temperatures of the two objects are the same. When the temperatures are equal we say the objects are in thermal equilibrium. At this point, the rate at which energy is transferred from one object to the other, is equal to the rate at which energy is transferred in the opposite direction.

Having looked at the scientific view of temperature and heat, the literature related to the different ideas children have about these two concepts is reviewed.

Kesidou and Duit (1993) reported that students explained temperature as a quantity that could be quantified and measured, but heat could not be quantified or measured. Some students viewed heat as an **intensive** property of a substance and temperature as a degree of heat. For example, a cup at room temperature possesses the same heat as the room itself. However, some students view heat as an **extensive** quantity and temperature as something that can pass from one body to another: therefore degrees in Celsius would mean the

amount of temperature transported.

Alternative ideas about temperature were also reported by Strauss (1977; in Brook et al, 1984). Investigations were done on a number of ideas about temperature among 200 children aged between 4 and 13 years. He found a U-shaped pattern in their responses, when asked to predict the final temperature of the water when equal quantities of cold water were mixed into a third container. The young and the oldest children predicted correctly that the water will remain the same, whereas the intermediate children predicted that the water would be more colder than before mixing. The U-shaped pattern of responses was common to the development of understanding of intensive physical quantities, where initial intuitive reasoning is replaced by partially quantified reasoning which develops into fully quantified reasoning, temperature being recognised as an intensive property. Strauss further found that students performed better when different temperatures were involved than when cold water was combined with more cold water.

Stavy and Berkovits (1980) reported similar results to those found by Strauss. They reported a conflict between children's qualitative reasoning and the quantitative reasoning when a certain quantity of cold water is added to more cold water. Children were able to predict that the temperature will be the same but when required to give the resultant temperature quantitatively, children added the two temperatures to give double the initial temperatures.

Investigations done by Driver and Russell (1982) and Erickson (1979) also revealed that some students associated temperature with volume. Adding equal quantities of water at equal temperature was predicted to result in water at a different temperature.

Student's conceptions of heat, make their understanding of thermal processes different from the scientist's. Poor conception of how thermal processes take place brings about serious confusion with temperature equalisation. To some students, temperature differences occur because of the heat inertia and the difference in qualities of the material which interact. One great uncertainty which developed from these misunderstandings is what is equalised in reaching thermal equilibrium, temperature, heat or energy?

Watts (1983) and Erickson (1979) investigated student's ideas about heat transfer. In describing temperature change in a heated metal rod, heat was said to have built up in one part of the rod then overflowed to another part. Some students said that heat travelled through air spaces in the rod. Explanations of this nature suggest the existence of difficulties in understanding change of phase, where in cases like melting and boiling, heating does not cause any temperature increase,

Brook et al (1984) carried out indepth investigations on student's ideas about change of state. A number of tasks related to phase change were investigated: these included 'frozen peas', 'potatoes', 'melting point', 'porous pot' and 'ice molecules'. The explanation on the five tasks required the underlying ideas 'energy is required to change state' and 'during change of state, the temperature remains constant, even though energy is transferred'. The results of this study showed that the frequency of student's correct ideas about temperature constancy during phase change decreased from frozen peas > potatoes > melting point > porous pot > ice molecules. This decrease suggested that aspects of the question context influenced the extent to which students drew on these ideas. It was simple for students to use the idea that energy is supplied to change state from a solid to a liquid to a gas, but the reverse case where energy is removed appeared considerably more difficult to understand. Again confusion between heat and temperature was evident. Some of the additional problems identified were the failure of students to use the particulate ideas in a coherent way, and the description of heat as having the characteristics of a fluid.

One of the topics which has been found to cause learning difficulties among high school students is chemical energy. Cohen (1987) reported that students fail to establish the link between temperature changes and energy changes. The confusion is at times brought about by the use of the term " to measure heat" when they mean to say "to measure temperature". Hence, the conception of how the change in temperature is linked to the change in energy is difficult. One other factor contributing to this, is the poor usage of the molecular mental picture or models in processes involving addition of energy to a substance.

Ben-Zvi and Cohen (1992) classified difficulties in learning about chemical energy into:

(a) Conceptual difficulties

Basically, the energy concept is too theoretical. Many students fail to link between energy changes and changes that occur at molecular level. The major difficulties are caused by the misunderstandings of concepts such as heat, energy and temperature, bond energies and specific heat capacities at molecular level. Other formal concepts contributing towards students difficulties are: the standard conditions, standard heat of formation and interpretation of Hess' Law. Many students fail to understand that bond formation alwa s produces energy, while bond dissociation always requires energy.

(b) Calculation of enthalpy changes

In many instances, students are able to play around with calculations of enthalpy changes, without understanding the meaning of their calculations. This has been evident from experimental problems, where students were required to calculate the heats of reactions from the experimental results. In calculating the heats of reactions, students need to differentiate between the **system and the surroundings**, but students experience serious difficulties in differentiating between the two terms, especially in homogeneous reactions.

Johnstone et al (1977a) studied student's ideas about the distinction between potential energy and kinetic energy. They found that students did not appreciate that at phase change the average kinetic energy of molecules is the same in the gas phase and liquid phase. The understanding of these concepts requires a thorough understanding of the microscopic description of what happens during phase change.

2.3 Thermodynamics: a multivariate topic

Thermodynamics is a multivariate topic, ntegrating basic concepts such as temperature, heat and energy. Furthermore students must be able to manipulate the different variables simultaneously. Many researchers report that most high school students fail to operate at the required cognitive level. Hence they find working with multivariable problems is a difficult task.

Rozier and Viennot (1991) studied student's reasoning in thermodynamics where multivariable problems were included. Their results indicate that students and even some teachers have got a tendency of reducing the number of variables so that they can work with one variable, forgetting the others. Sometimes two variables are combined. In this case two physical quantities seem to be stuck to one another, thus making one variable. For example; a common idea is that thermal motion is higher in gases than in liquids and higher in liquids than in solids. This would suggest that the mean distance between particles and the mean kinetic energy of particles, are seen as two physical quantities stuck to one another, hence giving the impression of adherence between kinetic and geometrical aspects. This is an idea that is even prevalent in some science textbooks.

Ben-Zvi and Cohen (1992) and Cohen (1987) designed a chemical energy teaching package, with the aim of overcoming the misconceptions which were described earlier on. Though the package was successful in eradicating some of the misconceptions, no improvement was observed with the working on a multivariate situation. This indicates that the package failed to help students to operate on Piaget's formal stage of operation.

Linn and Songer (1991) developed a teaching package , which was aimed at overcoming misconceptions about heat, energy and temperature across a broad range of situations, that is heating, cooling and phase change. Their results indicate that students were able to establish a little understanding of heat, energy and temperature only when prediction and observation experiments were used. Very few students could use what they had learned in the laboratory to interpret natural phenomena or situations that deal with heating and cooling effects. Though the learning package and teaching strategies persuaded students to use the kinetic molecular theory in explaining thermal processes, no student ever mentioned it in their explanations of the phenomena.

In general, the results reported by Linn and Songer (1991) are similar to those reported by Summers (1983) and Kesidou and Duit (1993). Students experience difficulties in explaining thermal processes because they do not know and understand the extensive and intensive nature of heat and temperature respectively. Their poor usage of the particle model in explaining thermal processes indicates another area of difficulties, which is the difference

between macroscopic properties and the microscopic ones. Students tend to transfer qualities of behaviour in the macroscopic world, thus failing to use the microscopic model to interpret the macroscopic world. Stavy and Stachel (1985) reported in their study with 9th grade Israeli students about properties of solids and liquids, that the students could not use a microscopic model to describe solids and liquids. Ramot (1992) noted a similar trend with tertiary chemistry students in South Africa on the concept of chemical structure. She noted the reason for this type of thinking to be childish ideas such as microscopic particles carry the properties of a substance. It was also attributed to the fact that students hold fragmented knowledge due to concepts not being properly linked in their minds.

2.4 Entropy and the second law of thermodynamics

Entropy is one of the thermodynamic quantities that help us to understand why chemical reactions occur. Before we discuss the difficulties encountered in learning this concept, we shall briefly discuss the scientific view of entropy and its role in chemical reactions.

In nature we come across changes which occur spontaneously and those which do not (non-spontaneous changes). In chemistry too, we are concerned with spontaneous reactions and non-spontaneous reactions. Spontaneous reactions take place without any outside assistance. Once such a change begins, it continues on its own. An example is the reaction between hydrogen and oxygen. Once the mixture is ignited, the reaction to form water continues until all of one of the reactants is consumed. A non-spontaneous change on the other hand must be continually helped along or it will stop. Spontaneous reactions can be exothermic or endothermic.

Change in energy is not the only factor that determines the spontaneity of a reaction. One other factor which determines spontaneity is the natural tendency towards disorder. For example when a drop of food colouring is added to a glass of water, it spreads in the water until a homogeneously coloured solution results. The particles of the food colouring and water tend to become randomly dispersed, so as to form a uniform mixture. This situation does not happen because the particles like to mix. It happens because independently the particles of the food colouring and water tend to disperse and become more disordered. The

situation of the particles dispersing is more probable to occur than a situation where the particles of the food colouring will be found at one place in the container. The food solution was formed because of the high probability of the particles to mix. In thermodynamics, the quantity related to probability is called entropy. Entropy is a measure of the disorder of the particles that make up the system and the dispersal of energy associated with the particles. It is given the symbol, S. Spontaneous processes thus occur when a less probable state changes to a more probable state. Spontaneous reactions thus occur when there is an increase in energy dispersal and/ or matter dispersal. Since systems tend to change spontaneously in the direction of greater probability, they tend to change spontaneously in the direction of greater entropy.

The entropy of a system depends on a number of factors. Knowledge about the factors that control the magnitude of entropy enable us to understand what factors condition the position of equilibrium and to explain why chemical reactions occur. The entropy of a system depends on the type and amount of a substance in a system and the state of the system.

(a) **The type of a substance**

Substances are composed of molecules with different structures and masses. From the molecular structure aspect, the degree of the movement of atoms and molecules affects the value of entropy of a substance. The more flexible is the movement, the greater the entropy. For example the standard entropies of gases are generally bigger than for liquids and solids. This is because particles in gases are more flexible in movement (rotational, translational and vibrational) than in liquids and solids.

Entropy increases with the mass of the particles. The heavier the particle, the more closely spaced energy levels the particle has. This increases the probability of the higher energy levels being occupied by quanta of energy. We have more different ways the same quantity of energy can be distributed among the energy levels.

(b) **Amount of substance**

Increasing the amount of a substance in a system increases the entropy of the system. For example two moles of water molecules has a higher entropy than one mole of water

molecules. By increasing the amount of a substance, one actually increases the number of possible microscopic arrangements of energy quanta in a system.

(c) **Temperature**

In general when the temperature of a system increases, so the entropy of the system increases too. This is because with increased total energy, there are more possible arrangements of that energy.

(d) **Volume**

In the case of gases entropy is dependent on the volume of the system. The smaller the volume occupied by a gas, the larger the distance between the energy levels, the lesser the probability that the higher energy levels will be filled with quanta of energy. This leads to a smaller entropy of the system.

What is the link between entropy and disorder?

The word "disorder" in thermodynamics is used to indicate the dispersing of energy throughout the energy levels of the particles in a system. Hence, when we talk about an increase in "disorder" we actually mean an increase in the probability of energy levels being occupied by quanta of energy in a system. An increase in disorder is not always caused by an increase in temperature; there are reactions which occur spontaneously due to an increase in entropy but taking place at a constant temperature.

Having looked at the scientific view of entropy. In the next section the difficulties and misconceptions associated with entropy and spontaneity of processes are reviewed.

Teaching and learning about entropy and the second law of thermodynamics is also associated with problems. Ribeiro (1992) describes her findings concerning university students' ideas about entropy and the second law of thermodynamics. The students' conceptions were tested after they had been successful in thermodynamics examinations. Ribeiro summarises students' views as follows:

(i) The majority of the students believed that entropy increases with the disorder of particles. They considered that disorder increased because the movement of the particles increased. In the context of thermodynamics, disorder is used to indicate permutational probability of the same quanta of energy being scattered over many energy levels to correspond with the macroscopic state. Some students related the idea of movement of particles with collisions, for some "less collisions" relates with less movement; for others less collisions related with "more movement". They related collisions with movement and by implication collisions between particles were related with entropy.

(ii) Almost all the students could remember the word microstate, but half of them could not remember any meaning for it. Only two students explained microstate in terms of arrangement of particles. The majority of the students did not relate microstate with disorder. They seemed to link entropy to microstate only very vaguely.

(iii) More than half of the students were not able to give an acceptable statement of the second law of thermodynamics. Some considered entropy to be conserved. The students did not relate the second law of thermodynamics with the spontaneous evolution of phenomena. Some considered attainment of equilibrium as the reason for spontaneous evolution. This is not surprising as their understanding of the second law was generally very superficial and incorrect.

(iv) The majority of the students were not able to explain why thermal equilibrium is established. Though they were able to explain it in terms of the increase of the overall entropy of both the system and the surroundings, they did not use the ideas of the dispersion of energy linked with the number of microstates to explain spontaneity of natural processes. This conclusion agrees with the report by Ben-Zvi et al (1990), from a class of tenth grade school pupils.

Johnstone et al (1977) in their research on the feasibility of teaching thermodynamics at school, report a tendency for students to confuse entropy with kinetic energy. Students were asked to consider a stretched elastic band at room temperature, which when released contracts spontaneously. The entropy of rubber increases as it contracts due to the nature of the molecular structures of rubber. When rubber is stretched, the spiral structure of the polymer is unravelled, leading to an increase in kinetic energy of the particles, but the entropy decreases because the polymer is now straightened, hence the movement of the polymer molecules becomes less. One student in two believed that for the entropy of rubber to increase, there must be a temperature increase. Increase in entropy is always equated with an increase in temperature, perhaps through some misconceptual notion of disorder. For a student who holds this belief, it may be difficult to understand that certain processes are accompanied by an increase in entropy even though they take place at constant temperature.

There are some simple general chemistry textbooks which actually foster misconceptions about entropy. These textbooks give definitions and explanations that are ambiguous, leading to conceptual difficulties. For example " entropy is a measure of chaotic dispersal of energy or a measure of disorder of a system". In this explanation, the idea that entropy is a quantitative property of a body is not emphasised. This renders the explanation vague in distinguishing the source of the disorder (Johnson, 1990; Wright, 1974; Lowe, 1988). Lowe interviewed a student studying chemistry major about his understanding of the relationship between entropy and disorder. This student had learnt that entropy is a measure of randomness or disorder in a system from his first year chemistry textbook. By then this student was able to understand the definition of entropy. His partial understanding of the disorder was evident when he was given problems to solve in physical chemistry. His idea of disorder was that entropy increases due to positional disorder or randomness of the molecules. According to this idea, an increase in disorder of the gas molecules is based on the space available for the molecules to move randomly. The bigger the volume, the higher the disorder or randomness of the molecules. This kind of idea caused difficulties when he was confronted with a situation where a gas was heated from 300 K to 400 K at constant volume. An increase in entropy for this change was seen as impossible because the molecules of the gas at 300 K and 400 K had the same random distribution or positional

arrangement of gas particles. An increase in disorder was seen as only possible when the volume of the gas could be increased.

The definition of entropy in many General chemistry books is very limited. Teachers and lecturers need to show the students the limitations of such definitions.

Students's criteria of deciding whether a reaction was spontaneous or not

Ribeiro et al (1990) interviewed 14 fourth year undergraduate chemistry students in connection with the criteria they use to determine whether a reaction had occurred and if it was spontaneous. Four experiments were demonstrated to them. Most students took a decision that a chemical reaction occurred when products or new substances were visible. They used mostly visual criteria. If a new substance was not seen forming, it meant that a reaction had not occurred.

The interpretation of spontaneity by these students was based on the everyday meaning of the word. The major criterion used here was the idea of the external interference on the system rather than thermodynamic criteria explained by the second law. Students argued that a reaction will be spontaneous if it is observable that the reaction occurs under certain conditions, without an external interference. Activation energy is regarded as an external interference. So a reaction was not spontaneous if activation energy had to be given. Here the students failed to distinguish between energy of activation and energy of the reaction. For example when iron filings burned with sulphur, the reaction was observed to be non-spontaneous because the reaction had to be initiated by heating. Endothermic reactions are believed to be non-spontaneous. The energy being transferred from the surroundings to the system is considered to be an interference. For example, the reaction of ammonium chloride dissolving in water is an endothermic reaction. A student answered "... I think it is not spontaneous because it needed heat from the surroundings ... if it was isolated, it would". Many students even though they knew the scientific criterion for spontaneity, did not use it unless they were asked to and then mostly found it difficult to accommodate it to their natural interpretation. They preferred to use the everyday explanation of spontaneity. When explaining why $\Delta G < 0$ is a criterion for a spontaneous reaction, two students used

the idea that everything goes to a state of minimum energy, but they were not clear of the type of energy they were referring to and they seemed confused.

Student 1: ... "because the system always goes to a minimum energy, ... I do not know if I can take the Gibbs energy as the value of the energy of the system."

Student 2:... "because everything goes to a state of minimum energy, if ..ergy of the products is less than the energy of the reactants it is natural that the reaction occurs spontaneously...the internal energy of the system and the Gibbs energy is the same thing."

Emphasis on the mathematical calculation of ΔG did not foster conceptual understanding of spontaneity. Students were able to calculate $\Delta G_{(re..ion)} < 0$, for the reaction of iron filings burning with sulphur. Half of the students (7) however said that even though $\Delta G < 0$, the reaction was not spontaneous.
Student:... "I go on saying that the reactio.' is not spontaneous...I am not able to understand why $\Delta G < 0$ and I still have to give energy..."

Student 12:... " I think it is not spontaneous, because when I mixed the iron and the sulphur they did not react ... perhaps I am confused about it"
Student 10:... " I believe more in ΔG. I do not know what to think but I believe more in ΔG...I go for ΔG... but only happened when I heated it...I do not know what to think".

The majority of the students were able to distinguish between ΔG and ΔH in their calculation of ΔG, but they were not able to explain the meaning of ΔG and ΔH nor why $\Delta G_{(reaction)} < 0$ is a criterion for spontaneity of a chemical reaction. They used the idea that ΔH compensates the value of -TΔS in ΔG = ΔH - TΔS, but the description of the conceptual relationship between these quantities did not exist. They were confused about the relationship between the different terms. Students were able to do the calculations correctly, but when they were faced with a problem involving real phenomena, they could not transfer to the situation the same concepts they used when solving theoretical problems. They preferred to use everyday life interpretations.

The understanding of free energy is based on a good understanding of basic concepts such as energy, temperature, heat. Firth (1969) describes the connection of these important ideas in understanding free energy in a pyramid:

free energy

enthalpy *entropy* *energy*

pressure *temperature* *volume* *work* *heat* *equilibrium*

Fig. 1. The pyramid of ideas that are dealt with in chemical thermodynamics
**Understanding of free energy comes by working from the base upwards.

2.5 Emphasis on mathematical presentation rather than conceptual understanding

Many students find thermodynamics to be difficult. One of the reasons mentioned is the difficult approach or presentation of the subject. Much of the thermodynamics is presented in the form of difficult mathematical equations. Students fail to see the chemistry that is hidden in the equations. Hence, their reasoning rests on the ideas of physics and mathematics rather than chemistry (Wright, 1974; Johnson, 1990).

Granville (1985) and Ribeiro et al (1990) identified several misconceptions which originated mainly in problem-solving strategies used by the university students. Teachers tend to emphasise a mathematical approach and hence students adopt the attitude of memorising equations and formulae in solving a problem. A problem is solved numerically by calculations and just arriving at the answer. Understanding of the underlying principles is not so important to them. They only concentrate on key words which are familiar to them in solving numerical problems emanating from a new situation. This usually creates difficulties as they often misuse the implications of these key words. Granville lists several examples of students' explanations using key words:

1. $\Delta E=0$ for an isothermal process (only true for an ideal gas). The difficulty lies in

students generalising this idea to be applicable to all phases of matter.
2.$\Delta S=0$ for an adiabatic process (only true for a reversible process). Students forget that the path must be reversible when integrating dU, dH, dS. The integrals of U, H and S are assumed to be path independent, and hence they forget that when integrating $dS=dQrev/T$ the path must be reversible. The significance of "rev" is easily forgotten.

Laidler (1989) also reported that students experience difficulties with the concept of reversibility. According to Laidler, this could be emanating from the difference in meaning of reversibility in thermodynamics and in its everyday usage. For instance, cooling is irreversible according to a scientist's point of view, but students regard it as reversible, because the substance will get warmed up again. This idea could further trigger the misunderstanding of " spontaneous processes" and the energy conservation principle.

3. $\Delta S>0$ for a spontaneous process. Here ΔS refers to the system and surroundings, or to the isolated system. Introduction of the Gibbs function causes confusion with students, because in the relation, $\Delta G=\Delta H - T\Delta S$, ΔS refers to the system only, isolated or not.
4. $\Delta G<0$ for a spontaneous reaction (only true for isothermal, constant pressure changes).

The points above seem to be important regardless of problem-solving. The basic argument is that thermodynamic relationships are only valid under certain conditions and students do not recognise this. They also do not see the importance of signs and subscripts.

Wright (1974) argued against the teaching of thermodynamics at high school level, because he felt that the topic is too complex and difficult for students to learn. However, Ogborn (1974), Morwick (1981) and Johnson (1990) contradicted Wright's ideas. They argued that this topic is essential in studying many scientific topics, hence it should be introduced at lower levels, but the teaching strategies and the content should be designed to suit the intellectual level of the pupils.

Ogborn (1974) Morwick (1981) and Johnson (1990) suggested that in the introductory phase of this topic, emphasis should be placed on heat flow and temperature while introducing entropy at A-level. They further suggested two possible ways of approaching it in the

classroom:

(i) Classical thermodynamics:

It is based on observable changes in macrostates, e.g. temperature, volume. In this approach the teacher should first establish understanding of concepts followed by the mathematical calculations. It can be first addressed from a non-mathematical point of view.

(ii) Statistical thermodynamics:

It is based on the principle that thermodynamic observable (macroscopic) quantities are averages of molecular properties. It is built upon the molecular interpretation of thermodynamic changes. Ogborn (1974) suggests that a teacher should start the students with something that can be visualised to some extent such as the motions of particles or sharing of lumps of energy among particles. Students can use statistics to count the number of ways in which energy can be stored in a system.

These two ways could be used without an intense mathematical approach. By so doing, students would be well prepared to tackle the topic at the more abstract level at the university.

Williams and Glasser (1991) suggested a rational teaching approach to thermodynamics at undergraduate level. They believe that one should first introduce the qualitative nature and the purpose of thermodynamics before the mathematical approach.

Johnstone, Macdonald and Webb (1977) reported conceptual difficulties in pupils (and perhaps with teachers) on the concept of Gibb's free energy as it is related to studying chemical equilibrium. Distinction between systems and surroundings to some students was a problem. This lead to problems in understanding the second law of thermodynamics. The overall results indicated that pupils had little or no conception of entropy relations even after tuition. They still held their intuitive ideas even when they had been through chemical thermodynamics lessons and examinations.

According to Morwick (1981), teachers also contribute towards students'difficulties. Most

high school teachers know that there are two driving forces behind the chemical or physical changes, observed in our experience, but the difficulties arise when teachers try to explain the urge for the maximum disorder labelled as "entropy". Many teachers at secondary schools choose not to touch the issue of entropy in detail, because they are scared of being confronted with its mathematical description; hence many students learn about entropy only at the university level.

2.6 Chemical equilibrium

Chemical equilibrium is fundamentally linked with chemical thermodynamics. There are two approaches to teaching chemical equilibrium. One approach is based on the concept of equal and opposite rates of reaction (widely used at high school level or introductory level of chemical equilibrium), while the other approach is from thermodynamics, which is based on the concept of free energy.

One of the principles that students have to learn among chemical equilibrium concepts is Le Chatelier's principle. The principle is used to predict the effect of changes in equilibrium conditions. The principle requires knowledge of the equation for the nett reaction in order to predict shifts in equilibria caused by concentration changes. On the other hand, the effects of changes in temperature are not easy to predict from the nett equation. An equilibrium can be disturbed by changing the temperature of the system. Changing the temperature results in a changed equilibrium constant. Many students are confused with this, and they believe instead that any change in reaction conditions will alter the equilibrium constant. In fact the change in pressure and concentration does not affect the equilibrium constant since the system adjusts itself to the changes leaving the constant unchanged. In order to predict the effect of changes in temperature, one needs to know whether the reaction is endothermic or exothermic. This is usually not deducible from only the knowledge of the equation for the nett reaction.

Extensive research on conceptions of chemical equilibria has been done. A lot of misconceptions has been revealed, which strongly suggest that pupils, students, student-teachers and experienced teachers must be having conceptual difficulties with chemical

equilibria and related thermodynamic concepts (Johnstone, Macdonald and Webb, 1977; Wheeler and Kass, 1978; Hackling and Garnett, 1985; Bradley, Gerrans and Long, 1990; Banerjee, 1991). The studies have shown that participants confused the descriptive (rates) and prescriptive (thermodynamics) meanings of reversibility. The descriptive rates definition that a reaction may proceed forwards and backwards was shown to be well understood, though the simultaneous occurrence of forward and reverse reactions at equal rates was not very well understood. This conceptual difficulty may be emanating from the misconception that an equilibrium system consists of two independent and separate compartments (left and right sides) rather than the one whole.

Johnstone, et al (1977a) identified a tendency in students to relate the magnitude of free energy change to the rate of reaction. A reaction for which free energy change is large is considered to occur rapidly. There is possibly a misconception related to the fact that the net rate of reaction in a system tends to zero as the equilibrium is approached because the value of ΔG tends to zero. Also the students were possibly drawing an analogy from the macro physical world where the further things fall the faster they go.

Banerjee (1991) identified misconceptions among undergraduate students and teachers on the areas relating rate with equilibrium. For example some teachers and students felt that for an exothermic reaction, when the temperature is decreased, the rate of the forward reaction will increase. Similarly they believed that increasing the temperature in exothermic reactions would decrease the rate of forward reaction. This conceptual difficulty arises because they try to interpret the rate using Le Chatelier's principle and thus confuse the rate and extent of reaction. Banerjee (1991) relate these conceptual difficulties with the curriculum which fails to expose students to thermodynamics when studying equilibrium. It should be emphasised that the equilibrium law depends on thermodynamics rather than on kinetics.

The above studies have also identified difficulties in distinguishing between potential and kinetic energy at the molecular level. If students have conceptual difficulties with the first law of thermodynamics, how will they deal with changes in enthalpy (which depends on changes in kinetic energy and potential energy) and other energy considerations in general?

The misconceptions and conceptual difficulties mentioned in this chapter show that the understanding of thermodynamics gained by many students at the pre-university and university level is generally superficial and incorrect.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The aim of this study was to investigate college of education student's conceptions of the second law of thermodynamics and its related concepts. The investigation did not attempt to induce conceptual change since no new teaching material was developed. The researcher wanted to find out if the students would learn effectively the more enriched and advanced treatment of chemical thermodynamics which the new syllabuses prescribed. It was necessary for basic ideas to be investigated so as to find out whether the conceptions students gained throughout their years of studying science formed a good foundation for learning about the second law of thermodynamics.

3.2 The sample

3.2.1 College of Education students and lecturers

The study was conducted at four colleges of education in the Northern and one in the Mpumalanga Province. All the colleges were formerly administered by the ex- Department of Education and Training. The initial sample was fifty six students in their third year of Secondary Teachers Diploma studies. Eight college of education science lecturers also took part in the initial survey. All the students were following the same syllabus. They also used a common general chemistry textbook written by Gillespie et al (1989).

The initial plan was to work with at least sixty students but due to the low enrolment of students following the science stream at colleges the sample was reduced. These colleges supply many schools with teachers. Mpumalanga has only one college enroling students for training in secondary science education. This problem was one of the incentives for the researcher to embark on this study, although it did not become the focus of the study.

The number of participants dropped to forty eight (students) during the administration of

the post-questionnaire because of unforeseen and uncontrollable circumstances for example, class boycotts. Only four colleges but twelve lecturers participated in answering the post-questionnaire and two in the interview session.

Interviews were conducted with only ten students. These students volunteered through the encouragement of their lecturers. It was a group of mixed ability. They were interviewed after they had done the topic on chemical thermodynamics and having answered the post-questionnaire.

3.2.2 The University of the Witwatersrand, College of Science 2nd year students

These students come from an educationally disadvantaged background. Their first year programme is stretched over a period of two years. These students have passed their matric with poor science subjects results but they have an ability to pursue studies in science and related fields. Their chemistry curriculum is similar to that of the Secondary Teachers Diploma at the colleges of education. Because of their background and the similarities in the chemistry curriculum a group of College of Science students was chosen as a pilot group. A tutorial group of nine students was involved. They completed the open ended questionnaire in the first phase before instruction and a post questionnaire. Though the teaching programmes of the College of Science and of the colleges of education differ, it was felt that it would be of interest to compare the two groups.

3.3 Preliminary identification of the problem areas or difficulties

(a) Informal discussions and interviews with college of education lecturers about chemical thermodynamics led the researcher to believe that conceptual difficulties about this topic exist among lecturers as well as students. It was necessary that these conceptual difficulties be identified. Only three lecturers agreed to be interviewed. Overall the results of these discussions revealed that concepts such as temperature, heat, energy were not well understood by students. Two lecturers also confessed that they had problems in teaching the first law of thermodynamics, which led to their hesitation in teaching the second law of thermodynamics.

(b) A workshop for college of education lecturers on the use of the particle model for introducing chemical thermodynamics was conducted in July 1992. It was timed so as to precede the teaching of the topic to students. A group of lecturers completed a questionnaire covering the three basic concepts of heat, temperature and internal energy. The results indicated that some of the lecturers had conceptual difficulties with these concepts. The views of lecturers in this regard served as the foundation for the development of questionnaires to be used in phases 1 and 2.

3.4 Development of test instruments

The test instruments used were questionnaires and interviews.

3.4.1 Questionnaires

The questionnaires were developed along the lines suggested by Treagust (1988) and based on previously identified students difficulties and misconceptions and the objectives of the STD (Secondary Teachers Diploma) syllabus. During the time of development very few relevant literature articles were available. The related literature available on topics such as chemical equilibria and chemical reactions was also used. (Rozier and Viennot, 1991; Linn and Songer, 1991; Ribeiro et al, 1990; Ribeiro, 1992; BenZvi et al, 1990; Johnstone et al, 1977; Summers, 1983)

The survey of knowledge and understanding tests used in the College of Science, Department of Chemistry, University of the Witwatersrand were also used in the development of questions. These tests consisted of multiple choice questions based on the objectives stipulated in the syllabus.The survey of knowledge tests are valid and reliable, and also cover much the same syllabus as the colleges of education. The data available from the informal interviews with the lecturers guided the researcher in designing and selecting items or questions for the pre- and post- questionnaires.

The questionnaires were designed to examine and identify the areas of difficulties and misconceptions before and after instruction. The pre-questionnaire was used mainly to examine the background of chemistry the students had from their previous physical science instruction and as the diagnostic for the different prerequisite concepts for the understanding

of the second law of thermodynamics.

Both the pre- and post questionnaires had sixteen multiple choice items. Each multiple choice item was followed by a blank space where the students were asked to give a reason why a particular option was chosen. This technique is advocated by Treagust (1988) and described in detail by Driver et al (1985). The most useful effect of the technique is that it further increases the validity and reliability of the research analysis when analogous instances from interviews and questionnaires are identified. This is also useful when the qualitative analysis is compared with the quantitative (Erickson 1979). Due to the small samples in this study, the analysis is largely qualitative.

The pre-questionnaire had also a section B which consisted of open ended items. Statements were given and students had to respond by indicating whether the statement is correct or not, explaining their answers. The responses given in the pre-questionnaire served as the foundation for the development of the post-questionnaire and guided the interviews. There was no section B in the post-questionnaire.

In both the pre- and post-questionnaires the items covered understanding of the following concepts: temperature, energy, phase change, spontaneity of reactions, free energy and entropy. In the pre-questionnaire scientific explanations of the last three concepts mentioned above were not expected. The preconceptions were expected to be non-scientific. But in the post-questionnaire some evidence of meaningful understanding was expected by the researcher. Because the pre-questionnaire was basically designed to examine the understanding of the prerequisite concepts for the learning of the second law of thermodynamics the items in the pre-questionnaire and post-questionnaire differed in some cases.

The distribution of the questions and the concepts is given in table 1 below:

Table 1. Distribution of the questions and the concepts in the questionnaires

concept	pre-questionnaire multiple choice question numbers	post-questionnaire multiple choice question numbers
temperature, heat and energy	1; 5	1; 3
phase change	2; 3; 4	2
equilibrium	6; 7	4
entropy	8; 14; 15; 16	5; 7; 8; 10; 15; 16
spontaneity	9; 10; 11; 12; 13	6; 9; 11; 12; 13; 14

3.4.2 The reliability and the validity of the questionnaire

Most of the items were selected from the survey of knowledge tests used by the university. These tests had been tested for validity and reliability previously . To make sure that the questions met the needs of the project and the level of the college of education participants, two senior science lecturers and a chemistry expert checked the clarity and difficulty of the questionnaires.

3.4.3 Interviews

Various methods aimed at identifying students' misunderstandings have been developed. Among these methods are interviews. Clinical interviews deal with a specific section of the topic which helps with the investigation of the entire topic. The clinical interviews are aimed at ascertaining the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions the individual holds and the perceived relationships among these conceptions. This approach was pioneered by Jean Piaget while investigating the nature and the extent of children's knowledge (Piaget, 1969).

The relationship between the data collected by testing and observation, i.e. qualitative and quantitative analyses, is made more valid because interviews focus on the natural mental inclination of the subject, which the other two methods overlook or falsify. Therefore interviews were used to support the explanations given in the questionnaires. It was also thought that it would make the study a more comprehensive piece of work, since the students would be more free and open to express their thinking and understanding verbally than on paper.

The subjects

Interviews were conducted im' 'ediately after administering the post-questionnaire. Only ten interviews were conducted. These students had answered both the pre- and post-questionnaires. The number of interviews was limited by the time constraints of both the researcher and the participants. One other factor which contributed towards the few interviews was the fact that participants were asked to volunteer and only ten students turned up. Five students came from one college whilst the other five were from another college. Therefore, students from only two colleges participated in this stage of the study. The other three colleges could not take part due to their domestic problems. The subjects varied in their intellectual ability. There were both very good students and average ones. Each student was interviewed by the researcher. The sessions lasted for approximately forty five minutes. The interviews were audiotaped for later analysis.

Clinical Interviews

Interviews were planned as outlined by Cohen and Manion (1989). The questions were semistructured, based on Piaget's (1969) clinical interview model.

The questions were based on everyday phenomena and also on classroom activities. The aim of selecting questions from both environments was to allow the subjects to use both the everyday explanations and the classroom or scientific ones, so as to make their explanations and understanding very clear. There were times when questions had to be repeated or the phrasing changed so as to give the subject a chance to comprehend what was being asked. Sometimes the researcher had to use the subject's mother tongue (Sepedi) in a question follow up to make the question understandable to the interviewee.

Three live demonstrations were conducted at the beginning of every interview session. The three demonstrations served as the starting point of the interviews. Questions were generated from the demonstrations. Students were given a chance of explaining the ' ,vations they had experienced from the demonstrations. Students who were unable to express their views verbally were encouraged to write their responses on paper. The interview protocol was flexible in this regard.

CHAPTER 4

ANALYSIS OF THE RESPONSES TO THE QUESTIONNAIRES

4.1 Introduction

In this chapter the results of the student's and lecturer's responses to questionnaires are presented. The items of the tests are reported in groups or individually according to the concept(s) under investigation. For each of the items there is a table representing the multiple choice options selected by the participants followed by the summary of the reasons or explanations for their choices. The reasons given by participants have been grouped into clusters according to sets of ideas they show as:

. acceptable

. alternative

. no response

The pre-questionnaire (appendix A) was used to identify the preinstruction level of knowledge that the students and lecturers had about the thermodynamic concepts under investigation. Some of the items in the pre-questionnaire were not repeated in the post-questionnaire.

The post-questionnaire (appendix B) addressed understanding of the concepts after instruction. This questionnaire was administered to college of education students and lecturers and also second year College of Science students at the University of the Witwatersrand.

Abbreviations used in the text

CEDS = college of education students

LECT = college of education lecturers

CSCS = College of Science students

* = correct option/ response

KE = kinetic energy

PE = potential energy

n = number of participants choosing a specific option

In the pre-questionnaire, there were 8 college of education lecturers and 56 college of education students. However, the post-questionnaire was administered to 12 college of education lecturers, 48 college of education students and 9 College of Science students. Though there was the same number of colleges between the administration of pre- and post-questionnaires, the number of college of education lecturers increased because there were more science lecturers interested in taking part in the study. Some of these lecturers did not teach STD 3 at the time but were teaching STD 1 and 2.

4.2 Analysis of responses to questions on different concepts

In the following analysis the questionnaire items have been grouped according to the principal concepts that they test:

A. Relationship between temperature, heat and energy

B. Chemical equilibrium

C. Entropy

D. Spontaneity

4.2.A The relationship between temperature, heat and energy

The connection between temperature changes and energy changes is one of the important aspects of understanding physical and chemical changes. It is important to identify the meanings and understanding of the participants in connection with these concepts: temperature heat and energy changes.

Item A1

Question 1 (pre-questionnaire and post-questionnaire)

This item tested the understanding of temperature at a microscopic level. Temperature change is a macroscopic phenomenon. Microscopically, a collection of particles possesses

different amounts of kinetic energy at different temperatures. This cannot be observed macroscopically, but we are able to use temperature, as a measure of the average kinetic energy of any collection of particles.

Question:

At the given temperature

A. *all substances have the same energy*

B. *all molecules have the same velocity*

C.* *the average kinetic energy of any collection of atoms is the same*

D. *the heat content per mole of all substances is the same*

E. *none of the above*

Table A1.1 Multiple choice options selected for item A1

	Pre-questionnaire		Post-questionnaire		
OPTION	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	10.7 (6)	0.0	14.7 (7)	0.0	11.1 (1)
B	7.1 (4)	12.5 (1)	2.1 (1)	0.0	0.0
C*	30.4 (17)	50.0 (4)	33.3 (16)	100 (12)	77.8 (7)
D	19.6 (11)	12.5 (1)	25.0 (12)	0.0	0.0
E	25.0 (14)	25.0 (2)	20.8 (10)	0.0	0.0
No response	7.1 (4)	0.0	4.2 (2)	0.0	11.1 (1)
Total	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

Table A1.1 indicates a marked improvement from pre-questionnaire (50%) to post-questionnaire (100%) by the lecturers choosing the correct answer. There was however very little improvement with CEDS students. Comparison of CEDS with CSCS in the post-questionnaire shows that CSCS performed much better that CEDS.

Options D and E were predominant wrong choices for CEDS in both the pre-questionnaire and post-questionnaire. This indicates that many CEDS students had a poor conception of the relationship between temperature and kinetic energy of the particles. Reasons given to the dominant options (*C, D and E) are presented in table A1.2

A variety of alternative reasons was given by students and some of the lecturers as indicated in table A1.2 below. The most common reasons among lecturers and CEDS was that all the molecules have the same speed and kinetic energy at a specific temperature. This was also a common reason for options C and E. To some students, same temperature meant that the substances had the same heat content. Temperature was regarded by some as a source of energy.

Table A1.2 Reasons given to item A1

Option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
C	**Acceptable** 1. Temperature is a measure of kinetic energy	1	0	1	7	0
	2. Individual particles possess different amounts of KE, therefore average KE is considered	1	2	1	0	0
	2. Average KE of a group of molecules is always the same at a given temperature	0	0	0	0	3
C	**Alternative** 1. All molecules at the same temperature have the same KE	4	1	2	3	3
	2. Absolute temperature is proportional to the velocity of the molecules	0	1	0	1	0
	3. All molecules move at the same speed	3	0	3	0	1
	4. Absolute temperature equals to the average KE of the molecules	1	0	2	0	0
	5. Temperature provide heat to the molecules	2	0	3	0	0
C	No response	5	1	4	0	0
D	1. All substances absorb the same heat at the same temperature	2	0	2	0	0
	2. All substances absorb the same temperature	3	0	0	0	0
	3. Heat content of a substance depends on temperature	0	0	2	0	0
	4. Heat is a measure of temperature	0	0	4	0	0
D	No response	7	0	3	0	0
E	1. All substances have different KE	5	0	1	0	0
	2. Molecules gain energy at the same rate	0	0	3	0	0
	3. Temperature is distributed evenly among all molecules resulting in the same energy content	3	0	1	0	0
E	No response	8	0	1	0	0

The findings in table A1.2 indicate that many students did not know exactly what the temperature measures. Temperature, heat and kinetic energy were sometimes used

interchangeably as if meaning the same thing, implying that students did not understand the difference between: (i) temperature and kinetic energy of the particles, (ii) temperature and heat.

The 'no response' category under explanations diminished substantially between pre and post-questionnaires. The explanations for making the correct choice did not improve between pre and post-questionnaires.

The word 'energy' was sometimes used indiscriminately. Participants would at times mention 'energy' without being specific, e.g. heat energy or kinetic energy. Perhaps this problem comes partly from direct translation of 'energy' from N-Sotho and Swazi. In many African languages the word 'energy' is not differentiated into different types. The word 'energy' may mean a lot of things such as 'power', 'force'. This may be inhibiting conceptual understanding of energy in scientific terms.

Item A2

Question 2 (pre-questionnaire only)

This item tested students' understanding of the energy changes during melting. It had been assumed that since CEDS had done the 1st law of thermodynamics at the 2nd year level, they would show a good understanding of a physical change that is accompanied by absorption of energy.

Question:

An example of an endothermic change is the

*A** *melting of a compound with a network structure*

B. *formation of a chemical bond*

C. *freezing of a liquid*

D. *expansion of an ideal gas into vacuum*

E. *mixing of concentrated sulphuric acid with water*

Table A2.1 Multiple choice options selected for item A2

	Pre-questionnaire	
OPTIONS	CEDS % (n)	LECT % (n)
A*	30.4 (17)	75.0 (6)
B	3.6 (2)	25.0 (2)
C	46.4 (26)	0.0
D	10.7 (6)	0.0
E	8.9 (5)	0.0
No response	0.0	0.0
Total	100 (56)	100 (8)

Lecturers performed well compared to the students.

Three quarters of the lecturers and one third of the students chose the correct option, A. Most students chose option C, which indicates that they believed that freezing was an endothermic change. No lecturer selected this option, which may indicate that students brought this misconception from school. Options B, C and E are in fact all examples of exothermic change.

Reasons given for the answers to question 2 are presented in Table A2.2.

Table A2.2 Reasons given to item A2

Option	Reasons	Pre-questionnaire frequency	
		LECT	CEDS
A	Acceptable 1. Energy absorbed causes melting 2. Melting occurs spontaneously	 4 2	 2 0
A	Alternative 1. Because temperature increased 2. The network structure has a high boiling point	 0 0	 1 1
A	No response	0	13
C	Alternative 1. Endothermic reactions feel cold like freezing 2. In freezing no energy is given off 3. Energy is needed for freezing 4. Endothermic reactions release heat 5. Melting occurs spontaneously, no energy is needed	 0 0 0 0 0	 10 5 2 2 2
C	No response	0	5

The results in table A2.2 indicate that the majority of the students could not relate melting with the absorption of energy. Most of the students who chose the correct option A did not

give reasons. Many students associated freezing of a liquid with an endothermic change (energy absorption) maybe because of perceptual, "sensational" observation of a cold body like the freezer compartment of a refrigerator. This may indicate that students were operating more on a macrolevel than microlevel. Failure to operate at both levels leads to difficulties in understanding the energy changes associated with physical changes.

One other difficulty observed is the use of the word 'reaction' instead of change. The example given is a physical change rather than chemical change. Some students referred to physical change as 'physical reaction'. Perhaps students do not understand the difference between physical and chemical change.

Item A3

Questions 3 (pre-questionnaire) and 2 (post-questionnaire)

This item tested understanding of the relationship between temperature and kinetic energy changes that take place in a solid substance before it starts to melt.

Question:

When a solid substance at 0 K is allowed to increase its temperature (but not so far as to melt), the component atoms

A. *increase their nuclear energy*

B. *decrease their rotational energy*

*C** *increase their vibrational energy*

D. *undergo dissociation*

E. *do not change their kinetic energy*

Table A3.1 Multiple choice options selected for item A3

Option	Pre-questionnaire		Post-questionnaire		
	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	5.4 (3)	0.0	4.2(2)	0.0	0.0
B	0.0	0.0	0.0	0.0	11.1 (1)
C*	58.9(33)	75.0(6)	62.5(30)	100(12)	88.9(8)
D	17.9(10)	12.5(1)	16.7(8)	0.0	0.0
E	10.7 (6)	12.5(1)	14.6(7)	0.0	0.0
No response	7.1 (4)	0.0	2.1(1)	0.0	0.0
Total	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

There was no marked improvement from the pre-questionnaire to post-questionnaire by the CEDS in contrast to their lecturers.

Comparison between CEDS and CSCS in the post-questionnaire shows that CSCS (88.9%) performed much better than CEDS (62.5%). Thus CEDS had a rather poor understanding of the relationship between temperature and kinetic energy at the microscopic level, even after instruction. This conclusion is supported by the reasons presented in table A3.2.

Table A3.2 Reasons given to item A3 (option C)

Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
	CEDS	LECT	CEDS	LECT	CSCS
Acceptable Though vibrational energy increases, the overall energy is not enough to cause melting	1	2	1	2	0
Internal energy increases but not reached the level of melting	0	1	2	3	0
Only the vibrational motion of particles is increased before the solid melts	5	0	2	2	4
Increased energy transferred to particles weakens the bonds but not enough to cause melting	0	0	2	1	0
Energy supplied is mainly used to increase vibrations of particles in a solid	5	0	10	0	0
Alternative Temperature, energy and heat used interchangeably	7	0	2	0	0
Molecules expand when temperature is increased	15	0	1	0	0
Molecules start to vibrate from stationary (at rest)	0	0	2	0	0
Vibrational energy has no link to KE hence the solid cannot melt	0	0	2	0	0
No response	0	3	7	3	4

Only the correct choice 'C' was analysed. The findings of table A3.2 show an improvement on the correct reasons given by CEDS and lecturers from pre-questionnaire to post-questionnaire. The 'no response' option for CEDS increased by 7 from pre-questionnaire to post-questionnaire. Half of the CSCS gave the correct reason whilst another half gave no response in the explanations.

Many of the alternative reasons given in table A3.2 indicate that CEDS were still operating at a macroscopic level rather than at microscopic level. For example, one of the common statements was; ..." molecules expand when temperature is increased" Though this idea was identified among 15 students in the pre-questionnaire as compared to one student in the post-questionnaire, the CEDS, did not always change to a correct understanding. The idea that kinetic energy is directly proportional to temperature is probably known, but the nature of kinetic energy changes is not known. Their level of understanding of molecular kinetic energy may be limited to standard 9 (grade 11) level, that is they only recognise translational kinetic energy.

The alternative ideas identified here show that these students might have conceptual difficulties in understanding effects of energy changes on phase change.

Item A4

Question 4 (pre-questionnaire only)

The question investigated the understanding of phase change (at microscopic level) when temperature is constant. This item is related to items A2 and A3 above.

Students were expected to state that the change of solid to liquid is endothermic and the energy absorbed is used to break intermolecular forces.

The intermolecular forces are broken down due to the absorbed energy.

Question:

When solid methane, CH_4, at -184°C (its melting point) is converted to liquid methane at the same temperature,

A. the methane molecules gain kinetic energy

B. C-H bonds are broken

C the intermolecular forces are weakened*

D. the methane molecules expand

E. the molecules decrease in potential energy

Table A4.1 Multiple choice options selected for item A4.

Option	Pre-questionnaire	
	CEDS % (n)	LECT % (n)
A	19.6 (11)	12.5 (1)
B	16.1 (9)	12.5 (1)
C*	51.8 (29)	75.0 (6)
D	5.4 (3)	0.0
E	5.4 (3)	0.0
No response	1.8 (1)	0.0
Total	100 (56)	100 (8)

The results in Table A4.1 show that the lecturers performed well while CEDS performed reasonably well. Among students all distractors attracted responses, with A and B being the most popular. Option A cannot be correct because there is no temperature increase. Participants who selected this option probably do not know that the energy required for the

change of solid to liquid is potential energy. Option B is a process that happens during a chemical change (breaking of intramolecular bonds) rather than in physical change. Option E is a process that takes place during freezing and not melting.

Of the twenty nine CEDS and six lecturers who selected correct option C, only fourteen and three respectively gave correct reasons. The reasons are presented in table A4.2.

Table A4.2 Reasons given to item A4

Option	Reasons	Pre-questionnaire frequency	
		CEDS	LECT
C	**Acceptable** 1. Intermolecular forces are weakened to allow molecules to slide around each other freely	14	1
C	2. Melting is associated with weakening of intermolecular forces	0	2
C	**Alternative** 1. When a solid like methane melts, carbon and hydrogen bonds break, thus separating H and C atoms	8	0
C	2. Weakening of intermolecular forces decreases the compactness of the component molecules	0	1
C	3. An increase in temperature leads to an increase in the strength of vibrations until molecules move apart	4	1
C	No response	7	2
A	1. An increase in K.E of the molecules results in 'dissociation' of the solid structure	4	1
A	2. Compactness of atoms is reduced	3	0
A	No response	4	0
B	1. C-H bonds should be broken before a solid could melt	3	1
B	2. High temperatures break the C-H bonds easily	2	0
B	3. Hydrogen bonds break because of vibrations and new bonds are formed	1	0

The findings in table A4.2 show that the most popular alternative idea shared by fourteen CEDS students was that carbon - hydrogen bonds will break during melting. Eight of these students chose option C rather than option B. Hence they confused intermolecular bonds with intramolecular bonds and the 51.8% CEDS choosing the correct answer is misleadingly high. This may indicate a misconception that melting is generally accompanied by a chemical change. Evidently some of the lecturers and students do not have a good understanding of phase change, especially at the microscopic level. In summary, where conceptual difficulties were identified were the differences between:

(a) 'intermolecular' and 'intramolecular' forces

(b) 'bonds' and 'forces' between molecules.

(c) 'temperature' and 'thermal energy'

(d) 'decomposition of substances and melting'

Item A5

Questions 5 (pre-questionnaire) and 3 (post-questionnaire)

This item tested students understanding of temperature difference and energy transfer.

Question:

When a piece of a metal is placed in a beaker of cold water, exchange of energy occurs until the metal and the water have the same

A. total kinetic energy

B temperature*

C. internal energy

D. heat capacity

E. quantity of thermal energy

Table A5.1 Multiple choice options selected for item A5

option	Pre-questionnaire		Post-questionnaire		
	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	0.0	0.0	2.1 (1)	0.0	11.1 (1)
B*	66.1 (37)	87.5 (7)	58.3 (28)	91.7 (11)	77.8 (7)
C	7.1 (4)	12.5 (1)	8.3 (4)	0.0	0.0
D	8.9 (5)	0.0	12.5 (6)	8.3 (1)	11.1 (1)
E	17.9 (10)	0.0	16.7 (8)	0.0	0.0
No response	0.0	0.0	2.1 (1)	0.0	0.0
Total	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

The results in table A5.1 show a decrease from pre-questionnaire to post-questionnaire in the percentage of the CEDS choosing the correct answer. CSCS performed much better than CEDS on the post-questionnaire. The lecturers showed improvement from the pre-questionnaire to the post-questionnaire (87% to 92%). The drop in performance by the

CEDS indicates a failure to clarify correctly the relationship between energy and temperature. This failure is confirmed by the alternative reasons presented in table A5.2. In the pre-questionnaire, thirty seven CEDS selected the correct option, but only ten gave the acceptable reason. The correct reasons given by CEDS in the post-questionnaire decreased to four out of twenty eight students. Probably therefore their selection of the correct answer was based on guesswork or memorisation. All the lecturers and CSCS choosing the correct answer gave acceptable reasons.

Only the correct option was analysed because there were many students and lecturers who chose it.

Table A5.2 Reasons given to item A5.2 option B

Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
	CEDS	LECT	CEDS	LECT	CSCS
Acceptable At thermal equilibrium the average kinetic energy of the particles in both objects will be the same	10	7	4	11	7
Alternative Internal energy of the block and the metal will be the same since they all have the same amount of heat energy	13	1	7	0	0
Temperature of the metal is transferred to water until both temperatures are the same	9	0	10	0	0
At equal temperature no 'diffusion' of heat is necessary	0	0	3	0	0
No response	5	0	4	0	0

One lecturer shared a common misconception with thirteen other students, that the internal energy of the metal block and water will be the same at equilibrium since their temperature was the same.

The other misconception shown here was the use of the terms 'temperature' and 'energy' interchangeably. For example the following statements were common:

" The temperature of the metal is transferred to water until both the temperatures are the same"

" The same amount of heat energy meant the same internal energy"

" Water gained the temperature "

" Temperature is shared equally"

CEDS also seem not to be able to differentiate between the different meanings of internal energy and thermal energy.

4.2.B Chemical equilibrium

The concept of chemical equilibrium was not initially planned to be part of the research but the researcher believed that students might have some thoughts and ideas which affected their understanding of thermodynamics.

Item B1

Question 6 (pre-questionnaire only)

Question:

In a chemical reaction equilibrium

A. *the balanced chemical equation is no longer true since the reaction does not go to completion*

B. *the concentrations of the reactants and products are equal*

C. *the internal energies of the reactants and products are equal*

D. *the mass of the substances on the left hand side of the equation equals the mass of the substances on the right hand side*

*E** *the reactants continue to form products, but the products reform the reactants at the same rate.*

Table B1.1 Multiple choice options selected for item B1

options	Pre-questionnaire	
	CEDS % (n)	LECT % (n)
A.	0.0	0.0
B	16.1 (9)	12.5 (1)
C	3.6 (2)	0.0
D	8.9 (5)	0.0
E*	71.4 (40)	87.5 (7)
No response	0.0	0.0
Total	100 (56)	100 (8)

The correct choice was the most popular with both the lecturers and students. Although the majority (40) of the students chose the correct option E, others opted for most of the other distractors. One lecturer and 9 students believed that the concentrations of reactants and products should be equal at equilibrium. This could be related to a problem of stoichiometry, because students explained that in a balanced chemical equation, the number of moles on the right hand side must be equal to the number of moles on the left hand side. Atom conservation was confused with concentration conservation.

Table B1.2 Reasons for option E

Option	Reasons	Pre-questionnaire frequency	
		CEDS	LECT
E	Acceptable 1. The equilibrium is dynamic and the rate of forming products is the same as the rate of the formation of the reactants 2. Free energy change of the reactants is the same as the products	14 1	3 0
E	Alternative 1. At equilibrium the concentration of the products is the same as the concentration of the reactants	9	1
	2. Forward reaction is equal to backward reaction	3	0
	3. Reactants and products are formed at the same time	2	0
	4. Same rate maintains that the equilibrium does not stop	3	1
	No response	8	3

Only 3 LECT and 15 CEDS gave acceptable reasons for choosing option E. The alternative reasons given here show that CEDS and some lecturers did not understand the dynamic

nature of equilibrium.

Certain words or terms were found to be used incorrectly by students: "rate" was confused with "time" and "rate of formation" with no "degree of formation". This incorrect use of terms probably has an effect on students misunderstandings of equilibrium, or else reflects these misunderstandings.

Item B2

Questions 7 (pre-questionnaire) and 4 (post-questionnaire)

Question:

Which of the following statements about a system at equilibrium is incorrect?

A. *The expression for the equilibrium constant may be deduced from the balanced chemical equation*

B. *The free energy of the system is at minimum*

C. *The position of equilibrium is temperature dependent*

D. *The value of the equilibrium constant under standard conditions can be calculated from standard free energy data*

*E** *The position of the equilibrium can be predicted from a knowledge of the enthalpies of reactants and products*

Table B2.1 Multiple choice options selected for item B2

option	Pre-questionnaire		Post-questionnaire		
	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	7.1 (4)	0.0	6.3 (3)	8.3 (1)	22.2 (2)
B	53.6 (30)	25.0 (2)	45.8 (22)	33.3 (4)	11.1 (1)
C	12.5 (7)	0.0	16.7 (8)	0.0	33.3 (3)
D	7.1 (4)	12.5 (1)	6.3 (3)	16.7 (2)	0.0
E*	8.9 (5)	37.5 (3)	16.7 (8)	41.7 (5)	33.3 (3)
No response	10.7 (6)	25.0 (2)	8.3 (4)	0.0	0.0
Total	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

The results in table B2.1 show that CEDS improved only slightly to 17% correct. The lecturers also showed only a slight improvement to 42% in the post-questionnaire.

Comparison between CEDS and CSCS on the post-questionnaire shows that CSCS again performed better than CEDS. The overall performance on this item was however generally poor. Less than 50% of all students and lecturers chose the correct answer. One would expect that there would be a significant improvement after teaching the chemical thermodynamics topic, but that was not the case. Nearly all the distractors, with 'B' being predominant among CEDS, were chosen by a number of participants. Perhaps part of the poor performance was contributed by the fact that the question required the students and lecturers to select an incorrect statement rather than the correct one.

The explanation analysis was done only for the correct (E) and the predominant wrong (B) options.

Table B2.2 Reasons given to item B2.

option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
E	Acceptable 1. Enthalpies enable us to calculate free energy change but it has no effect on the equilibrium constant	0	0	1	3	2
	2. position of the equilibrium can be predicted from standard free energy	0	0	3	0	0
E	Alternative 1.The number of moles of reactants and products should be equal	1	0	1	2	0
	2. Change in enthalpy is used to predict direction of spontaneity	0	0	1	0	1
E	No response	4	2	2	3	0
B	1. Free energy change must be at maximum	8	0	13	0	0
	2. Free energy depends on the change in enthalpy of the reaction	1	0	1	0	0
	3. Free energy depends on temperature and not equilibrium	1	0	1	0	0
	4. Free energy has no effect on the attainment of equilibrium	4	0	6	0	0
B	No response	16	2	1	4	1

The reasons given in table B2.2 show that most of the participants among all the groups have conceptual difficulties relating to equilibrium and thermodynamics. Many CEDS gave no reasons in the pre-questionnaire but did in the post-questionnaire. Unfortunately the reasons they offered were rarely correct. The majority of students who selected option B

thought that at equilibrium the change in free energy had to be a maximum. This view was common among CEDS both before teaching and after. It is acceptable that students performance in the pre-questionnaire on item B2 should be poor because they were not previously taught the second law of thermodynamics. A greatly improved performance was therefore expected on this item after having been taught thermodynamics.

4.2.C Entropy

Item C1

Question 5 (post-questionnaire only)

This item tested students ability to identify processes associated with an inc ase in the entropy of the system.

Question:

In which of the following processes does the total entropy of the system increase?

A. *Air-conditioning a house*

B. *Separating coins by denomination*

C.* *Making a bottle of lemonade or a glass of Kool-Aid drink*

D. *Putting together a jigsaw puzzle*

E. *Packing a refrigerator*

Table C1.1 Multiple choice options selected for item C1

	Post-questionnaire					
OPTION	CEDS %	(n)	LECT %	(n)	CSCS %	(n)
A	52.1	(25)	41.7	(5)	66.7	(6)
B	20.8	(10)	0.0		0.0	
C*	14.6	(7)	33.3	(4)	22.2	(2)
D	4.2	(2)	8.3	(1)	0.0	
E	4.2	(2)	8.3	(1)	0.0	
No response	4.2	(2)	8.3	(1)	11.1	(1)
Total (n)	100 (48)		100 (12)		100 (9)	

Kool-Aid is a common South African drink in powder form. It is mixed with water to make a refreshing beverage.

All participants performed badly in this item. Only 14.6%, 33.3% and 22.2% of CEDS, LECT and CSCS respectively selected the correct answer. The results show that though the performance was generally poor, the CSCS performed slightly better than the CEDS.

In all categories of participants, the majority selected option A as indicated in table 5.1 above. This indicates that though the participants have learnt and even taught entropy (in the case of lecturers) they could not identify that the dissolution process, forming lemonade or Kool Aid drink from the powder form, is associated with an increase in the entropy of the system. The mixing of the water molecules and lemonade or Kool Aid molecules to form a solution increases the entropy of the system.

Though there were four lecturers, seven CEDS and two CSCS selecting the correct answer, C, in the multiple choice section, only two LECT, one CEDS and one CSCS gave the acceptable reason. (The reasons are presented in table C1.2)

The most prevalent alternative reason given for option A, was that as the house is air-conditioned, the air particles are disordered throughout the house as more air flows in. Some further explained that dust particles, which were initially settled and orderly, were set to random positions all over the house. This idea may come from the daily experience of what is seen when wind blows dust all over the place. The choice may also be a consequence of failing to take account of the focus on the system. The summary of the participants reasons is presented in table C1.2

Table C1.2. Clusters of reasons given for item C1

Option	Reason	Post-questionnaire frequency		
		LECT	CEDS	CSCS
C	Acceptable 1. Kool-Aid is a solid. Adding water distributes the Kool-Aid particles throughout the water to form a solution, occupying space between the liquid particles, thus increasing the entropy of the system.	2	1	1
C	No response	3	6	1
A	1. Conditioning makes air particles to move faster, randomly and more disordered 2. More air flows in at constant volume and high pressure 3. Air particles move faster, more collisions at a higher rate 4. Hot air is driven out	5 0 0 0	8 3 7 2	4 2 0 0
A	No response	0	5	0

The descriptions given for option A indicate that the participants preferred to use the kinetic theory to describe the positional state of particles but they could not use it correctly so as to link it with the changes in the entropy of the system. In general, the poor performance on this item shows a very limited ability to interpret everyday phenomena in terms of entropy change.

Item C2

Question 7 (post-questionnaire only)

This item tested participants understanding of the reason why the entropy of the gas increased when the temperature of the gas was increased. How do students relate temperature change to entropy change?

Question:

Suppose we have a mole of gaseous neon in a 20 l container at 300 K. We then heat it at a constant volume to 400 K. The entropy of the gas increases

A. because the average kinetic energy of the atoms increases

B. because of the increase in temperature

C. because heating increases the internal energy of the atoms

D. because of the increased possible number of ways a system has to store energy*

E. because the atoms are moving more randomly than before

Table C2.1. Multiple choice options selected for item C2

	Post-questionnaire		
Option	CEDS % (n)	LECT % (n)	CSCS % (n)
A	16.7 (8)	25.0 (3)	0.0
B	18.8 (9)	0.0	44.4 (4)
C	16.7 (8)	0.0	0.0
D*	4.2 (2)	0.0	33.3 (3)
E	41.7(20)	66.7 (8)	22.2 (2)
No response	2.1 (1)	8.3 (1)	0.0
Total (n)	100 (48)	100 (12)	100 (9)

The performance by all participants was very poor but the CSCS performed much better than CEDS. No lecturer chose the correct option. The students who managed to get the answer correct were perhaps just guessing. This is evident from the reasons presented in table C2.2., only one of the three CSCS students choosing the correct option also giving the correct reason. No CEDS gave the correct reason. The majority of the lecturers (8) and CEDS (20) chose option E, while more CSCS (4) chose option B. It had been given in the question that temperature increased, so the participants choosing B actually restated what was initially given.

From the reasons given in table C2.2 it is clear that the majority of the participants believe that as temperature is increased entropy will also increase because molecules gain more kinetic energy which results in more randomization of molecular motions. For these participants, randomization of the motions of particles leads to an increase in entropy. It is true of course that kinetic energy increases with temperature but they were expected to use the idea that entropy increases due to increased possible ways a system has to store energy.

Another difficulty identified here is in connection with the relationship between entropy and disorder. There existed a belief among some students that an increase in entropy is actually the cause of disorder in a system.

Table C2.2. Summary of the reasons given for item C2

Option	Reason	Post-questionnaire frequency		
		CEDS	LECT	CSCS
D*	Acceptable More ways of distributing and storing quanta of energy	0	3	1
D*	No response	1	1	1
Others A	Alternative 1. Temperature increases kinetic energy, randomness, collisions, speed and disorderliness of particles	6	0	0
B	" " " "	6	0	0
C	" " " "	3	0	0
E	" " " "	19	10	2
A	2. Speed, randomness and disorder of particles depend on entropy	2	2	0

The alternative explanations given in table C2.2 show that many of the participants did not really understand why the entropy of the gas increased when temperature was increased. This is disappointing, especially after the section on entropy was taught. Similar difficulties were identified in the post-questionnaire item C1.

Item C3

Question 8 (pre-questionnaire and post-questionnaire)

This item investigated if participants were able to identify changes in entropy of a chemical reaction system, given the reaction equations.

The options in the pre-questionnaire were slightly different from the post-questionnaire. This was done in order to reduce chances of guesswork from the pre-questionnaire responses.

Questions:

Pre-questionnaire:

Which of the following reactions is accompanied by a large increase of disorder of the system?

A. $2H_2(g) + O_2(g) \rightarrow 2H_2O\ (l)$

B.* $FeSO_4.7H_2O(s) \rightarrow FeSO_4(s) + 7H_2O(g)$

C. $N_2(g) + 3H_2(g) \rightarrow 2NH_3\ (g)$

D. $(NH_4)_2SO_4\ (aq) + BaCl_2\ (aq) \rightarrow BaSO_4\ (s) + 2NH_4Cl\ (aq)$

E. $CH_4(g) + 2Cl_2(g) \rightarrow CH_2Cl_2\ (g) + 2HCl\ (g)$

Post-questionnaire:

A. $H_2\ (g) + S(s) \rightarrow H_2S(g)$

B*. $Ni(CO)_4(l) \rightarrow Ni(s) + 4CO(g)$

C. $2Al(s) + 3O_2(g) \rightarrow Al_2O_3(s)$

D. $MgCO_3\ (s) \rightarrow MgO(s) + CO_2(g)$

E. $CH_4(g) + 2Cl_2(g) \rightarrow CH_2Cl_2\ (g) + 2HCl(g)$

Table C3.1. Multiple choice options selected for item C3

	Pre-questionnaire		Post-questionnaire		
Option	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	5.4 (3)	12.5 (1)	2.1 (1)	0.0	0.0
B*	33.9 (19)	50 (4)	18.8 (9)	33.3 (4)	55.6(5)
C	21.4 (12)	12.5 (1)	2.1 (1)	0.0	0.0
D	19.6 (11)	0.0	31.3 (15)	25.0 (3)	33.3(3)
E	10.7 (6)	12.5 (1)	43.8 (21)	33.3 (4)	11.1 (1)
No response	8.9 (5)	12.5 (1)	2.1 (1)	8.3 (1)	0.0
Total(n)	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

Participants were required to look at the state of substances as given in the reaction equations in order to identify the reaction with the largest increase in disorder of the system. The explanation of the correct choice in the pre-questionnaire, is that $FeSO_4.7H_2O(s)$ after dehydration forms 7 molecules of water in gaseous form. The water molecules in the gaseous state have a larger freedom of movement (rotational and translational, which increases ways of storing energy) than in the solid state. In the solid state $FeSO_4.7H_2O$ units are concentrated in a relatively small volume and are in fixed positions (only vibrational motions are available). The solid substance is more ordered with a lower entropy than a gas. So changing from a solid reactant to gaseous products results in an increased disorder of the system.

The performance of both the CEDS and lecturers in the pre-questionnaire was generally

weak. Only 33.9% (19) CEDS and 50% LECT chose the correct answer. All the distractors received attention from both groups of participants. The predominant distractors chosen were C and D, chosen by 21.4% (12) and 19.6% (11) of students respectively. In both D and C the entropy of the system decreased. No acceptable reasons were given by those who chose the correct multiple choice answer. Many participants left the reasoning section on the questionnaire incomplete. One should remember that at the stage when the pre-questionnaire was administered the CEDS had no formal teaching about the second law of thermodynamics. The ideas about the change of entropy in chemical reactions after instruction are analysed in the next paragraph.

In the post test most of the options differed from those in the pre-questionnaire. The performance was generally worse among both CEDS and lecturers. The CSCS (55.6%) scored much better than the lecturers and CEDS in the post-questionnaire.

Unlike in the pre-questionnaire, more participants in the post-questionnaire (33% of LECT and 44% of CEDS respectively) opted for distractor E which was common to the two tests. An element of guesswork probably existed among many participants. The reasons given were mostly incorrect, indicating that there is a lack of ability to identify entropy changes in chemical reactions. Some participants argued that since air is lighter, (air meant gas) therefore the 'air' will move faster, therefore increasing the degree of disorder of a gas as compared to solids, which are heavier. Based on this idea one student said:" because particles in a gas are smaller, they would move faster, therefore, increasing its entropy". For the participants, entropy is strongly associated with the speed and density of particles. This idea was also evident during interviews, where small molecules were taken to result in a higher entropy because of their size and mass. In fact bigger molecules will result in a higher entropy because, there are more ways of energy quanta to be stored in the more closely-spaced energy levels.

Table C3.2 Reasons given for option *B

Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
	CEDS	LECT	CEDS	LECT	CSCS
Acceptable 1. More gas molecules are formed in the products, thus leading to an increase in the entropy of the system	2	2	5	1	4
2. A change of phase from liquid to gas is associated with an increase in entropy	0	2	0	3	1
3. Energy is required to change the solid into a liquid or gas. An increase in energy causes an increase in the disorder of a system	0	0	1	1	0
Alternative 1. When a solid dissociates into a gas and a solid, the space between the molecules increases, thus allowing for an increase in disorder of the molecules	3	0	0	0	0
No response	11	0	3	0	0

The acceptable reasons given by the participants were scientifically incomplete. Some participants mentioned that a change from a liquid to a gas was associated with an increase in entropy. However none of them correctly explained why gases have a higher entropy than liquids and solids. Those who mentioned that there were more moles of gas produced also did not give the reason why an increase in the amount of substance is associated with an increase in entropy. These results show that participants did not understand well the factors which cause changes in the entropy of a chemical reaction system.

Here again there is a large decrease in number of 'no responses'. The question is whether the incidence of guessing is less when the number of 'no responses' decreases? Even when the percentage for the correct choice is not greatly improved, one often finds big decreases in % 'no response'. Perhaps after instruction they have gained definite ideas, which unfortunately are often wrong.

Item C4

Question 10 (post-questionnaire only)

Participants were required to identify the change of entropy of both the system and the surroundings when a chemical reaction occurs.

Question:

In which of the following reactions is there an increase in the entropy of the surroundings but a decrease in the entropy of the system?

(i) $CuSO_4.5H_2O(s) \rightarrow CuSO_4.H_2O\ (s) + 4H_2O\ (g)$ $\Delta H > 0$

(ii) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ $\Delta H < 0$

(iii) $2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$ $\Delta H > 0$

(iv) $3O_2(g) \rightarrow 2O_3(g)$ $\Delta H > 0$

(v) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ $\Delta H < 0$

A. *(i), (iii) and (v)*

B.* *(ii) and (v) only*

C. *(iii) and (v) only*

D. *(iii) only*

E. *All of the above reactions*

Table C4.1 Multiple choice options for item C4

	Post-questionnaire		
Options	CEDS % (n)	LECT % (n)	CSCS % (n)
A	6.3 (3)	16.7 (2)	11.1 (1)
B*	68.8 (33)	83.3 (10)	66.7 (6)
C	8.3 (4)	0.0	0.0
D	12.5 (6)	0.0	11.1 (1)
E	0.0	0.0	0.0
No response	4.2 (2)	0.0	11.1 (1)
Total (n)	100 (48)	100 (12)	100 (9)

All participants performed well on this question. However the reasons given for the correct choice of option B were mostly incorrect, as indicated in table C4.2 below. The reasons given show that there are misunderstandings concerning the relationship between enthalpy and entropy of a system. Some students thought that ΔH was similar to ΔG, and hence whenever they saw ΔH they simply referred to it as change in free energy.

The correct criterion to use in identifying the reaction with a decrease in entropy of the

system is to compare the number of moles produced with that of the reactants. A decrease in the number of moles is associated with a decrease in entropy of the system. Another criterion is to look at the states of the reactants and products. Entropy decreases from gas to liquid to solid.

Table C4.2. The reasons given for option B

Option	Reasons	Post-questionnaire frequency		
		CEDS	LECT	CSCS
B	Acceptable			
	(i) Because of the decrease in the number of moles produced in the products as compared with the reactants. There has been a change of state from gas to liquid in the case of reaction (v).	4	3	4
	(ii) Because ΔH of the reactions is less than zero, the heat released increased the entropy of the surroundings, reducing that of the system.	17	5	2
	Alternative			
	(i) Because entropy of the system is less than zero. (that is $\Delta H \equiv \Delta S$)	2	0	0
	(ii) There is more randomness of the surrounding than the system (this implies randomness ≡ entropy)	1	0	0
	(iii) Particles of the reactants are more randomly moving than clustered particles of the products	3	0	0
	(iv) A negative ΔH results in a negative ΔG	2	0	0
	No response	4	4	0

The reasons given in Table C4.2 show that a reasonable number of participants choosing the correct option B (8 lecturers, 6 CSCS and 21 CEDS) gave acceptable reasons.
Two of the CEDS believed that ΔH is equivalent to ΔS and another 2 believed that $\Delta G < 0 \equiv \Delta H < 0$. This belief may cause incorrect understanding of other concepts such as spontaneity of processes.

The incorrect, indiscriminate use of words such as 'randomness' may cause misunderstandings about the relationship between entropy and randomness of the particles. In the interviews, 'randomness' in spatial arrangement of particles was often referred to as one of the factors affecting the entropy of a system.

Items C5 and C6

Questions 15 and 16 (pre-questionnaire and post-questionnaire)

In these questions, students were asked to choose diagrams or models that described the relationship between change in entropy of the system and that of the surroundings. The diagrams are microscopic representations of initial and final situations for a number of processes. (Diagrams are in the appendices A and B, last page of the questionnaires).

Item C5

Question 15 (pre-questionnaire and post-questionnaire)

Question:

15. The pairs of diagrams in which the process represented must involve a decrease in entropy of the system is\are:

A. 4 only*

B. 2 and 5 only

C. 1, 3, 4 and 5 only

D. none

E. all of them

Table C5.1 Multiple choice options selected for item C5.1

	Pre-questionnaire				post-questionnaire					
Option	CEDS %	(n)	LECT %	(n)	CEDS %	(n)	LECT %	(n)	CSCS %	(n)
A*	57.1	(32)	75.0	(6)	77.1	(37)	75.0	(9)	100	(9)
B	25.0	(14)	0.0		12.5	(6)	8.3	(1)	0.0	
C	8.9	(5)	0.0		4.2	(2)	0.0		0.0	
D	1.8	(1)	0.0		0.0		8.3	(1)	0.0	
E	0.0	(0)	0.0		0.0		0.0		0.0	
no response	7.1	(4)	25.0	(2)	6.3	(3)	8.3	(1)	0.0	
Total (n)	100	(56)	100	(8)	100	(48)	100	(12)	100	(9)

The performance of all the participants in this item was satisfactory. The percentage of CEDS choosing correctly increased from 57 to 77 whilst the percentage of lecturers choosing the correct option remained at 75. It seems it was fairly easy for all the

participants to select diagrams that represent a decrease in the entropy of the system. CSCS scored even better than the lecturers and CEDS on the post-questionnaire.

It seems that the majority of the students choosing the correct option in the pre-questionnaire were just guessing. This is indicated by the number of students (9) giving wrong reasons and the number of CEDS (10) who did not respond to the reasoning section at all. Only thirteen out of thirty two CEDS gave the correct reasons in the pre-questionnaire, while 20 out of 37 did so in the post-questionnaire. Seven out of the nine CSCS gave the correct reasons. These reasons are presented in table C5.2.

Table C5.2. Summary of reasons given for option A

Option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
A	Acceptable The diagram shows that the system changed from a state of disorder to a more ordered one	13	5	20	7	7
A	Alternative 1. Molecules of the system move more randomly making the products to be less disordered	0	0	3	0	0
	2.There is a decrease in KE and an increase in PE of the particles	9	0	1	0	0
	3. The system moves from gaseous state to a solid state	0	0	0	1	0
	4. The system goes into a state of enthalpy	0	1	0	0	0
A	No response	10	0	8	3	0

Initially nine of the CEDS choosing A stated that the diagram represented a decrease in the particles's kinetic energy and increase in their potential energy. However after instruction their conception changed, with more students giving the correct reasons.

One college lecturer and two CSCS shared the idea that the correct diagram represented a phase change from gas to solid. Probably they linked the model with the states of matter rather than with entropy changes as asked in the question. Again if we were to consider their reasons separately, their explanations would still be wrong because the diagrams would represent a substance changed from gas to liquid and not a solid.

Item C6

Question 16 (pre-questionnaire and post-questionnaire)

In this item, participants were asked to identify the diagrams that represent a decrease in entropy of the surroundings.

Question:

The pairs of the diagrams in which the process represented must involve a decrease in entropy of the surroundings is/are:

A. *4 only*

*B** *2 and 5 only*

C *1,3,4 and 5 only*

D *none*

E *all of them*

Table C6.1 Multiple choice options selected for item C6

	Pre-questionnaire				Post-questionnaire					
Option	CEDS %	(n)	LECT %	(n)	CEDS %	(n)	LECT %	(n)	CSCS %	(n)
A	19.6	(11)	25.0	(10)	20.8	(10)	8.3	(1)	11.1	(1)
B*	35.7	(20)	25.0	(2)	62.5	(30)	41.7	(5)	66.7	(6)
C	5.4	(3)	0.0		2.1	(1)	0.0		0.0	
D	21.4	(12	25.0	(2)	6.3	(3)	41.7	(5)	11.1	(1)
E	5.4	(3)	0.0		0.0		0.0		0.0	
No response	12.5	(7)	8.3	(4)	8.3	(4)	8.3		11.1	(1)
Total (n)	100	(56)	100	(8)	100	(48)	100	(12)	100	(9)

Item C6 was similar to item C5 except that in this case the question was concerned with the entropy change of the surroundings. The performance of all the groups in both pre-questionnaire and post-questionnaire was lower in this item as compared to item C5 (See table C5.1 and C6.1). However, when comparing the pre-questionnaire and post-questionnaire, there was a noticeable increase in the number of participants choosing the correct answer. The % CEDS choosing correctly increased from 36% to 62.5% while the

lecturer's increased from 25% to 41,7%. However, though the lecturers improved, the post-questionnaire percentage correct was still lower than 50%. The CSCS performed slightly better than CEDS in the post-questionnaire.
The general improvement in performance may be due to guessing.

Table C6.2 Reasons given for item C6 option B

Reasons	Pre-questionnaire		Post-questionnaire		
	CEDS	LECT	CEDS	LECT	CSCS
Acceptable 1. Energy from the surrounding is taken up by the system, thus leading to a decrease in the entropy of the surroundings	4	1	10	3	3
Alternative 1. The entropy of the system and surrounding decreases because the process in endothermic	0	0	4	0	2
2. There is no diagram which shows disorder of the system	10	0	0	0	0
3. Entropy increases to accommodate change in the entropy of the surrounding	0	1	4	0	0
No response	6	0	8	2	1

There was only a moderate change in the number of participants giving the correct reason (see table C6.2). One would expect that after instruction, more of them would be able to give the correct reason. Out of 20 CEDS choosing the correct option in the pre-questionnaire, only 4 gave the correct explanation. In the post-questionnaire, 30 CEDS chose the correct option in the multiple choice section but still only 10 gave acceptable reasons.

The overall results from items C5 and C6 indicate that the participants had difficulties in using the diagrams to predict entropy changes of the system and the surroundings.

Item C7

Question 14 (pre-questionnaire only)

This item was intended to test the knowledge about the effects of temperature change on some thermodynamic quantities of a system.

Question:

Which of the following statements about the effects of increasing temperature on thermodynamic quantities is correct?

A. The enthalpy of a substance increases

B. The free energy of a reaction either increases or decreases

C. The degree of disorder of a reaction decreases

D. The disorder of a substance decreases

E. The enthalpy change of a reaction remains roughly unchanged

Table C7.1 Multiple choice options selected for item C7

	Pre-questionnaire			
Option	CEDS %	(n)	LECT %	(n)
A.	14.3	(8)	25.0	(2)
B.	3.6	(2)	12.5	(1)
C*	26.8	(15)	0.0	
D*	25.0	(14)	37.5	(3)
E.	23.2	(13)	0.0	
No response	7.1	(4)	25.0	(2)
Total (n)	100	(56)	100	(8)

This item has two acceptable answers, C and D. Comparison of the performance of CEDS and LECT at this stage shows that very little understanding exists. This is indicated by the number of student-teachers and lecturers who got the multiple choice answer correct. Only two correct explanations were given in the reasoning section by students (see table C7.2). No lecturer completed the reasoning section.

It is acceptable that students may not know the effect of temperature on all thermodynamic quantities before they are taught about these quantities. It is expected of lecturers however to be able to give the correct explanations.

It has been revealed in this item that some students have misunderstandings concerning fundamental concepts such as temperature and heat. Some of them regard temperature as a catalyst, whilst others could not differentiate between heat and temperature. Their explanations are given in table C7.2. Disorder is more associated with the speed of particles

than with entropy.

Table C7.2 Reasons given for item C7 options C and D

Option	Reasons	Pre-questionnaire frequency	
		CEDS	LECT
C	Acceptable degree of disorder of a system increases with temp	1	0
C	Alternative 1.Degree of disorder of a system increases because temperature acts as a catalyst	2	0
	2. An increase in kinetic energy leads to an increase in disorder	4	0
	3. Disorder increases because there is a phase change in the reaction	1	0
	4. Entropy is caused by a change in temperature	7	0
C	No response	0	0
D	Acceptable Temperature change is not a direct proportion of entropy change but an increase in temperature is associated with an increase in entropy	1	0
D	Alternative 1. Disorder results in an increase in heat	2	0
	2. Disorder means molecules gain kinetic energy and then move faster	6	0
D	No response	6	3

4.2.D Spontaneity

Item D1

Questions 9 (pre-questionnaire) and 6(post-questionnaire)

This item tested participant's knowledge and understanding about conditions necessary for chemical reactions to occur spontaneously. The idea here was to check if the participants could relate energy dispersal to spontaneous processes.

Question:

A chemical system changes spontaneously when

A. *the system liberates heat to the surroundings*

*B** *energy is dispersed in the change*

C. *elements form compounds*

D. *heat is applied to get it started*

E. *reactants mix homogeneously*

Table D1.1 Multiple choice options selected for item D1

	Pre-questionnaire		Post-questionnaire		
Option	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	12.5(7)	0.0	62.5 (30)	50.0 (6)	11.1 (1)
B*	12.5 (7)	25 (2)	10.4 (5)	25.0 (3)	33.3 (3)
C	44.6(25)	37.5 (3)	10.4 (5)	0.0	0.0
D	16.1 (9)	0.0	0.0	8.3 (1)	11.1 (1)
E	12.5 (7)	12.5 (1)	16.7 (8)	16.7 (2)	33.3 (3)
No response	1.8 (1)	25 (2)	0.0	0.0	11.1 (1)
Total (n)	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

In both the pre-questionnaire and post-questionnaire the outcome was unsatisfactory. Only 13% and 25% of the CEDS and lecturers, respectively selected the correct option in the pre-questionnaire. There was little or no change in percentage of the CEDS and lecturers choosing the correct option in the post-questionnaire. The CSCS again performed better than the CEDS and lecturers on the post-questionnaire.

The predominant distractor chosen in the pre-questionnaire was "C", which indicates that the majority of the participants believed that the formation of compounds from elements is spontaneous. This is generally true, but is obviously not expressing an underlying principle.

The predominant distractor shifted to "A" in the post-questionnaire for CEDS and lecturers. This suggests partial understanding of what should have been learnt and taught respectively. The CSCS preferred distractor E. Again homogeneous mixing of reactants may be spontaneous, but it is not expressing an underlying principle.

In the reasoning section, correct reasons were given by the 3 CEDS out of the 7 choosing the correct option in the pre-questionnaire. One lecturer out of 2 gave an acceptable reason in the pre-questionnaire. In the post test, only 1 CEDS and 2 CSCS gave acceptable reasons. No lecturer gave an acceptable reason in the post-questionnaire. Most of the lecturers left blank spaces.

Table D1.2 Reasons given for item D1

Option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
B*	Acceptable 1. According to the second law of thermodynamics energy must be dispersed within the system for a reaction to be spontaneous	3	0	1	0	2
	2. If the energy dispersed in a system gives ΔG negative, then the reaction becomes spontaneous	0	1	0	0	0
B*	Alternative 1. Dispersed energy keeps the reaction going	3	0	1	0	0
	2. Because spontaneous reactions are exothermic, they liberate heat to the surroundings	0	1	1	2	1
	3. The difference in energy state of the reactants and products lead to spontaneous reactions	0	0	1	0	0
B*	No response	0	5	1	1	0
A	Alternative 1. Because reactants are in a higher energy state, so they react spontaneously to release energy	0	0	3	0	0
	2. All exothermic reactions are spontaneous	0	3	14	3	0
	3. No external force causing the system to liberate heat to the surrounding in spontaneous reactions	0	0	7	0	0
	4. Energy liberated by the system determines the chemical reaction	1	0	3	0	0
	5. Spontaneous reactions imply formation of new bonds and compounds as products	2	2	0	0	0
	6. Because elements share valence electrons	17	2	0	0	0
A	No response	0	2	1	0	0

Many of the students not only chose A but then explained that exothermic reactions are spontaneous because heat is liberated. Some students stated that for a reaction to be spontaneous, heat must be supplied to the system to get it started. To some students, the

word spontaneous meant an immediate "response" or taking place rapidly. These explanations reflect the choices in the multiple choice question.

Looking at the results one senses that the participants were actually just using their perceptual judgement to determine conditions necessary for a reaction to be spontaneous.

Item D2

Question 9 (post-questionnaire)

This item is similar to item D1 above. Students had to identify a factor associated with spontaneous reactions.

Question:

Spontaneous reactions occur because

A. reactants do not require activation energy to initiate the reaction

B. of the difference in electronegativities

C. the energy of the reactants is lower than that of the products

D. the energy of the reactants is higher than that of the products

E the total entropy increases*

Table D2.1 Multiple choice options selected for item D2

	Post-questionnaire		
options	CEDS % (n)	LECT % (n)	CSCS % (n)
A	41.7 (20)	50.0 (6)	11.1 (1)
B	4.2 (2)	0.0	0.0
C	12.5 (6)	0.0	0.0
D	25.0 (12)	33.3 (4)	11.1 (1)
E*	14.6 (7)	16.7 (2)	66.7 (6)
No response	2.1 (1)	0.0	11.1 (1)
Total (n)	100 (48)	100 (12)	100 (9)

The responses given by the participants in table D2.1 indicate the majority of college of education students (20) and lecturers (6) believe that spontaneous reactions do not require

activation energy. This is a misconception, since activation energy is used to overcome an energy barrier and not to make an overall reaction occur. Another prevalent misconception among the CEDS and lecturers was the idea that all spontaneous reactions are exothermic. This idea is incorporated in distractor D. Only 14.6% CEDS and 2 lecturers chose the correct answer, with the CSCS (66.7%) again performing much better.

In the reasoning section, the College of Science students showed a good understanding of the fact that spontaneous reactions occur because of the overall increase in the entropy of both the system and the surroundings together. The lecturers and college of education students showed poor understanding of the concept. The predominant reason for the choice A was that no activation energy is required to start a spontaneous reaction. This reason was given by eighteen (18) students. This idea was predominant also in the interviews. A summary of the variety of other alternative reasons given by participants is shown in table D2.2.

Table D2.2. Reasons given for options E and D

Option	Reasons	Post-questionnaire frequency		
		CEDS	LECT	CSCS
E*	Acceptable 1. According to the second law of thermodynamics, the total entropy should increase	0	1	4
	2. Spontaneous reactions occur in the direction of increasing entropy	2	1	1
E*	Alternative 1. Molecules collide more readily to form reactants	1	0	0
	2. ΔH and ΔS are negative, ΔG will be positive and the reaction will be spontaneous	1	0	0
	3. Entropy increases because the energy of both the reactants and products increases	2	0	0
E*	No response	1	0	1
D	Alternative 1. Because the potential energy of the products is negative, therefore spontaneous reactions are exothermic	7	2	0
D	2. Spontaneous reactions tend to move towards minimum energy	2	2	0

It is evident that the majority of the college of education students and lecturers did not understand the factors responsible for spontaneous reactions.

Item D3

Question 10 (pre-questionnaire only)

This item aimed to test for the misconception that change in enthalpies can be used to determine the spontaneity of a reaction.

Question:

Which of the following reactions will occur in the direction written?

(i)	$CuSO_4.5H_2O \rightarrow CuSO_4.H_2O + 4H_2O$	$\Delta H > 0$
(ii)	$N_2 + 3H_2 \rightarrow 2NH_3$	$\Delta H < 0$
(iii)	$2NH_3 \rightarrow N_2 + 3H_2$	$\Delta H > 0$
(iv)	$3O_2 \rightarrow 2O_3$	$\Delta H > 0$
(v)	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	$\Delta H < 0$

Table D3.1 Multiple choice options selected for item D3

	Pre-questionnaire	
Option	CEDS % (n)	LECT % (n)
A. (i), (iii) and (v)	12.5 (7)	12.5 (1)
B. (ii) and (v) only	37.5 (21)	25 (2)
C. (iii) and (v) only	7.1 (4)	0.0
D. (iii) only	7.1 (4)	0.0
E. All of the above reactions	19.6 (11)	50 (4)
No responses	16.1 (9)	12.5 (1)
Total (n)	100 (56)	100 (8)

This item was faulty. The states of the substances were not given and there was no correct answer given among the options. This item was therefore not used in the post-questionnaire.

The results indicate that all the distractors received attention, with the most prominent being E among the lecturers and B among the students. Distractor B shows that only exothermic reactions will occur spontaneously while distractor E indicates that both endothermic and exothermic reactions will occur in the direction indicated. In fact enthalpies alone cannot determine the direction of spontaneity. One needs to know something about the change of

entropy of the system, but this item did not provide the necessary information.

In the reasoning section, there was no response from the lecturers while a few students gave alternative reasons for option B. Only one student gave the acceptable reason that change in enthalpy cannot be used as the only criterion to determine spontaneity. (See table D3.2 below).

Table D3.2 Reasons given by CEDS for item D3

Reason	Pre-questionnaire frequency CEDS
Accepted	
ΔH cannot determine spontaneity on its own	1
Alternative	
1. Both reactions (ii) and (v) favour the forward direction when ΔH<0 and the energy is at minimum	5
2. Spontaneous reactions are accompanied by ΔH<0	3
3. Only exothermic reactions will occur in the direction indicated, hence they are spontaneous	5
4. All reactions go to completion, therefore they are spontaneous.	3

Item D4

Question 11 (pre-questionnaire and post-questionnaire)

This item addressed the characteristics of a spontaneous reaction.

Question:

Which of the following statements about thermodynamic spontaneity is correct?

A. *spontaneous reactions all occur at a rapid rate*

*B** *for a spontaneous reaction, $\Delta G < 0$*

C. *for a spontaneous reaction, $\Delta S_{(syst)} > 0$*

D. *spontaneous reactions all go to completion*

E. *for a spontaneous reaction, $K < 1$*

Table D4.1 Multiple choice responses to item D4

	Pre-questionnaire		Post-questionnaire		
Option	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A	16.1(9)	0.0	4.2 (2)	8.3 (1)	0.0
B*	33.9(19)	25.0(2)	72.9 (35)	50.0 (6)	88.9 (8)
C	7.1(4)	50.0(4)	16.7 (8)	8.3 (1)	0.0
D	21.4(12)	0.0	6.3 (3)	16.7 (2)	11.1 (1)
E	5.4(3)	0.0	0.0	8.3 (1)	0.0
No response	16.1(9)	25.0(2)	0.0	8.3 (1)	0.0
Total (n)	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

The results on table D4.1 show an improvement in performance from the pre-questionnaire to post-questionnaire by both the CEDS and lecturers. CEDS improved from 33.9% to 72.9% while lecturers improved from 25% to 50%. In the post-questionnaire, CSCS (88.9%) once again performed better than the CEDS and lecturers.

Lecturers were expected to perform better on this item since they were due to teach the section a couple of weeks after the pre-questionnaire. Distractor C was the most prominent among lecturers but not among the students. There was a strong belief among the students that all spontaneous reactions go to completion. To some students "completion" meant no precipitate was formed. Formation of a precipitate was associated with a non-spontaneous reaction. This was evident also in the pre-questionnaire question 10. This indicates that these students used perceivable characteristics of a reaction as criteria for determining whether a reaction is spontaneous or not. Students looked at spontaneity from the macroscopic point of view.

In the reasoning section (pre-questionnaire), only 2 lecturers and 8 CEDS gave acceptable reasons for choosing option B, by confirming that ΔG should be negative for a reaction to be spontaneous (see table D4.2). In the post-questionnaire many more CEDS gave acceptable reasons.

A variety of alternative reasons was given in the post-questionnaire. This is presented in table D4.2.

Table D4.2 Reasons given by students and lecturers for correct option B

Option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
B	Acceptable					
	1. For a reaction to be spontaneous, ΔG must be negative	6	2	20	2	2
	2. Free energy decreases towards equilibrium	2	0	2	2	1
B	Alternative					
	1. Spontaneity favours minimum energy	0	0	0	1	1
	2. According to Gibb's law, the total entropy of the system increases to make $\Delta S = \Delta G$	4	0	0	0	2
	3. Because free energy of the reactants is greater than that of the products	4	2	0	0	0
	4. Because ΔG is negative and ΔH and ΔS are positive	0	0	2	0	0
	5. A spontaneous reaction must be exothermic	0	0	3	0	0
	6. Because free energy change is high in spontaneous reactions	0	1	0	0	0
B	No response	2	0	5	1	3

The common alternative reasons identified for option B imply:

(i) **$\Delta G < 0$ was taken to be the same as $\Delta H < 0$.** This reason was given by four students and one lecturer. For these participants the heat released in a reaction shows that the reaction is spontaneous.

(ii) **$\Delta G < 0$ is equated with $\Delta S < 0$.** Four students displayed this belief. According to these students, for a reaction to be spontaneous there must be a state of little disorder at the beginning of the reaction and hence $\Delta S < 0$.

Perhaps this difficulty arises from the fact that enthalpy and free energy are both energy-related concepts and students cannot differentiate them.

Item D5

Questions 13 (pre-questionnaire) and 12 (post-questionnaire)

This question tested ideas about endothermic change, with the melting of ice as an example of an endothermic change which occurs spontaneously. They also had to determine the sign of ΔG in a spontaneous process that has reached equilibrium. When ice is melting, ΔH is positive because the changing of ice to liquid water is an endothermic change. ΔS is positive

because the phase change from solid to liquid is associated with an increase in disorder of the system. However, at 0°C, the overall change in free energy, ΔG brought about by changing some ice to water is zero because $G_{liquid\ water} = G_{ice}$.

Question:

Which of the following is correct for the phase change

$H_2O(s) \rightleftarrows H_2O(l)$ at 0°C ?

	ΔH	ΔS	ΔG
A.	-	-	+
B.	-	+	0
C.	+	+	-
D*.	+	+	0
E.	-	-	0

Table D5.1. Multiple choice responses to item D5

	Pre-questionnaire		Post-questionnaire		
Options	CEDS % (n)	LECT % (n)	CEDS % (n)	LECT % (n)	CSCS % (n)
A.	3.6 (2)	0.0	20.8 (10)	0.0	0.0
B	37.5 (21)	25.0 (2)	16.7 (8)	0.0	0.0
C	25.0 (14)	37.5 (3)	37.5 (18)	25.0(3)	33.3(3)
D*	12.5 (7)	0.0	20.8 (10)	58.3(7)	55.6(5)
E	1.8 (1)	25.2 (2)	4.2 (2)	8.3(1)	0.0
No response	19.6 (11)	12.5 (1)	0.0	8.3(1)	11.1(1)
Total (n)	100 (56)	100 (8)	100 (48)	100 (12)	100 (9)

The results presented in table D5.1 show a great improvement in the percentage of lecturers choosing the correct option D. Little improvement was observed with CEDS. In both the pre-questionnaire and post-questionnaire, less than 50% of the CEDS chose the correct option. The CSCS again performed better than the CEDS.

However, though there was an improvement in the multiple choice section, the majority of the CEDS gave wrong reasons. Only 1 out of 14 and 4 out of 10 CEDS gave acceptable

reasons in the pre-questionnaire and post-questionnaire respectively. All CSCS and 5 out of 7 lecturers gave acceptable reasons in the post-questionnaire (see table D5.2).

Options B and C were the predominant choices of the CEDS in the pre-questionnaire and post-questionnaire respectively. The summaries of reasons given for these choices (B and C) are presented below.

Summary of reasons given for choice B in the pre-questionnaire:

(i) $\Delta G=0$ means that total energy is conserved during phase change [3 students]

(ii) Because the process is spontaneous, $\Delta H<0$, energy is released during the phase change from solid to liquid [2 students]

(iii) $\Delta G=0$ because temperature changed from negative to zero point. [1 student]

(iv) $\Delta G=0$ because the difference between ΔH and ΔS must be zero for the process to be in equilibrium [1 student]

Seven students did not give reasons, six reasons had no sense and one was uncertain.

Summary of reasons for choice C in the pre-questionnaire:

(i) Change in free energy is negative because the change is spontaneous [5 students]

(ii) Change is endothermic because ΔH is positive [3 students]

(iii) ΔS is positive because the system moves from ordered to disordered state [3 students]

Three students did not give reasons.

Summary of reasons for choice C in the post-questionnaire:

(i) At 0°C the water melts spontaneously [2 students]

(ii) Free energy is negative because entropy is positive, therefore the change is spontaneous [6 CEDS and 2 lecturers and 2 CSCS]

(iii) Free energy is always negative in spontaneous processes [2 students]

(iv) Free energy is negative because change in enthalpy is positive [3 students]

(v) Restatement [1 student]

(vi) No reason [3 lecturers and 4 students]

Table D5.2 Reasons given to item D5 for correct option D

Option	Reasons	Pre-questionnaire frequency		Post-questionnaire frequency		
		CEDS	LECT	CEDS	LECT	CSCS
D	Acceptable 1. At 0°C the system is at equilibrium because $\Delta G_{ice} = \Delta G_{water}$ (most acceptable)	0	0	2	5	5
	2. The system is at equilibrium (partially correct)	0	1	1	0	0
D	Alternative 1. $\Delta G = 0$ because ΔS (positive) is the only dominating factor for determining spontaneity	0	0	0	0	2
D	2. Because ΔH is positive	0	0	2	0	0
D	3. Because ΔG is spontaneous at low temperatures (0°C)	0	0	1	0	0
D	4. ΔG turns to zero when entropy increases	0	0	1	0	0
D	5. $\Delta G = 0$ because no energy is added or released from the system	0	0	1	0	0
D	No response	6	0	2	2	0

Item D6

Question 14 (post-questionnaire only)

This item tested the understanding of the conditions necessary for predicting whether a reaction will be spontaneous or not.

From the information given, ΔH and ΔS are positive, but the value of ΔS is high. The reaction will be spontaneous at high temperatures only. At high temperatures, the $T\Delta S$ is the predominant term in the equation $\Delta G = \Delta H - T\Delta S$. This will make ΔG negative. An endothermic reaction may be spontaneous therefore if it is accompanied by a large increase in the entropy of the system.

Question:

A certain chemical reaction has a ΔH of +122 kJ/mol and ΔS of 231 $JK^{-1}mol^{-1}$. At what temperature does this reaction proceed spontaneously?

A. at all temperatures

B. at 0 kelvin

C. at high temperatures only*

D. at low temperatures only

E. this reaction will not proceed spontaneously at any temperature

Table D6.1 Multiple choice options selected for item D6

Options	Post-questionnaire		
	CEDS % (n)	LECT % (n)	CSCS % (n)
A	14.6 (7)	0.0	33.3(3)
B	8.3 (4)	0.0	0.0
C*	43.8 (21)	50.0 (6)	55.6 (5)
D	18.8 (9)	8.3 (1)	11.1 (1)
E	8.3 (4)	25.0 (3)	0.0
No response	6.3 (3)	16.7 (2)	0.0
Total (n)	100 (48)	100 (12)	100 (9)

The CEDS once again performed less well on this item than the lecturers and CSCS . Thus the CEDS, even after instruction still have difficulties in predicting spontaneity for an endothermic change though given the necessary information. Very few students gave the correct reasons compared to the number which selected the correct option in the multiple choice section (see table D6.2 below). Some of the explanations given were not sensible and other students did not give reasons at all.

All the lecturers and CSCS selecting option C gave the correct reasons. Unfortunately, these represented only about half these categories of respondents.

Table D6.2 Reasons given to item D6 for correct option C

Option	Reasons	Post-questionnaire frequency		
		CEDS	LECT	CSCS
C	Acceptable From the equation $\Delta G = \Delta H - T\Delta S$, a higher temperature favours a negative ΔG when the given ΔH is positive	5	5	5
	Alternative 1. There is more maximum energy at a higher temperature 2. Spontaneous reactions occur when ΔH is negative 3. Since ΔH is high, more energy is needed to start the reaction	6 2 3	0 0 0	0 0 0
	No response	5	0	0

The alternative reasons given by CEDS in table D6.2 above, confirm the existence of difficulties experienced by students in relation to the effect of temperature on spontaneous changes. There exists a belief that spontaneous reactions occur when ΔH is negative. A

positive change in enthalpy is seen as a barrier for a reaction to occur spontaneously, hence the reason: "... ΔH is high, more energy is needed to start the reaction". The existence of such ideas, makes it difficult for students to understand that ΔG is highly dependent on the temperature of the system, as is the case with item D7.

Item D7

Question 12 (pre-questionnaire only)

The item tested the preconceptions that existed about the second law of thermodynamics.

Question:

Which one of the following is an incorrect statement of the second law of thermodynamics.

A. *Every system which is left to itself will, on the average change to a condition of maximum probability*

B. *In a spontaneous process, the total disorder of the system is increased*

C. *Heat cannot spontaneously pass from a colder body to a hotter body*

D. *The state of the maximum probability is the most stable state for a system*

*E** *All the heat energy obtainable from a system can be converted into work*

Table D7.1 Multiple choice options selected for item D7

	Pre-questionnaire	
Option	CEDS % (n)	LECT % (n)
A	7.1 (4)	0.0
B	17.9 (10)	0.0
C	33.9 (19)	12.5 (1)
D	7.1 (4)	0.0
E*	21.4 (12)	62.5 (5)
No response	12.5 (7)	25.0 (2)
Total (n)	100 (56)	100 (8)

Not surprisingly lecturers performed much better than the students. It is acceptable that a low percentage of students (21%) chose the correct option before instruction. A number of strange explanations were given by both lecturers and students making the correct choice E (see table D7.2 below). The fact that all distractors received support may indicate a great

deal of guess work by students at this stage. Many of the students chose C as a wrong statement. On the contrary, this is actually what the second law explains.

Table D7.2 Reasons given for item D7

Option	Reasons	Pre-questionnaire frequency	
		CEDS	LECT
E*	Acceptable 1. Most systems are not 100% efficient in converting heat energy to work 2. Some of the energy is released to the surroundings	 3 2	 4 0
E*	Alternative 1. Heat energy cannot be converted to useful work 2. Second law of thermodynamics has nothing to do with conversion of energy to work done	 3 2	 0 0
E*	No response	0	1
C	Alternative 1. Spontaneous reactions occur due to an increase in randomness of the system 2. Heat energy occurs as a result of an increase in kinetic energy of the molecules and not according to the second law	 2 10	 0 0

Item D8

Question 13 (post-questionnaire only)

This question on spontaneity was used to determine whether students, through their understanding of factors affecting spontaneity, would identify a way in which non-spontaneous reactions could be made to occur. The options provided are prominent misconceptions with the exception of E.

One important property of free energy change for a reaction is that it can tell us how much useful work can be derived from a reaction. For a non-spontaneous reaction ΔG tells us the minimum amount of work that must be done in order to make the process occur. The free energy change in spontaneous reactions can be utilized for the performance of work on non-spontaneous reactions.

Question:

A non-spontaneous reaction can be made to occur by

A. Adding a catalyst

B. Giving it an activation energy

C. *Supplying it with reactive molecules*

D. *Addition of heat*

*E** *Performing some work on the reaction continuously*

Table D8.1. Multiple choice options selected for item D8

	Post-questionnaire		
Option	CEDS % (n)	LECT % (n)	CSCS % (n)
A	35.4 (17)	16.7 (2)	0.0
B	27.1 (13)	41.7 (5)	22.2 (2)
C	2.1 (1)	0.0	22.2 (2)
D	18.9 (9)	16.7 (2)	11.1 (1)
E*	16.7 (8)	16.7 (2)	44.4 (4)
No response	0.0	8.3 (1)	0.0
Total(n)	100 (48)	100 (12)	100 (9)

The performance by all participants on this item was poor with less than half of the participants choosing the correct option. The most preferred choices were A and B for CEDS and B for lecturers. Thus a considerable number of students as well as lecturers hold the misconceptions that catalysts and activation energy can make a non-spontaneous reaction occur. Table D8.2 below shows the different reasons given by students and lecturers to back up their choices. Only three CEDS gave acceptable reasons. The alternative reasons given indicate two serious areas where the participants, especially CEDS, have conceptual difficulties:

(i) the role of activation energy and catalysts in chemical reactions is not correctly understood. This problem was also identified in the pre-questionnaire.

(ii) the conditions necessary for reactions to be spontaneous are not known.

Table D8.2 Reasons given for item D8

Option	Reasons	Post-questionnaire frequency		
		CEDS	LECT	CSCS
E*	Acceptable 1. Continuous work applied will make energy available for a non-spontaneous reaction to occur (eg; electrolysis of water - example stated by one lecturer)	3	2	4
E*	Alternative 1. Activation energy is the minimum energy required to start a non-spontaneous reaction	5	0	0
A	A catalyst is used to supply the system with activation energy	17	0	0
D	Adding heat energy shows that non-spontaneous reactions are endothermic	5	0	0

It is evident that participants confused reaction kinetics issues with chemical thermodynamics issues. The ideas identified in this item were also identified in the interviews.

4.3. Analysis of responses to section B of the pre-questionnaire

All the questions in this section addressed views about SPONTANEITY

This section was administered for the college of education lecturers and students only. Students were not expected to know exactly what makes some reactions spontaneous and others non-spontaneous. The main objective was to identify the ideas students have about spontaneity before formal instruction. Participants had to answer true or false to the statements given and also give reasons for their answers. There was no section B in the post-questionnaire. Some of the ideas identified in this section were used in the post-questionnaire.

The total number of students responding to the questionnaire was fifty four out of fifty eight. Nine lecturers responded.

Question 1

Only exothermic reactions are spontaneous:

Table 1a. Number of participants that opted for "true" or "false"

True		* False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
2	28	6	22	1	4

The stem of this item indicates a common misconception. Exothermic and endothermic reactions may both be either spontaneous or non-spontaneous. Thus change in enthalpy on its own does not determine the spontaneity of a reaction.

However about half of the students and a quarter of the lecturers thought that change in enthalpy can be used to determine if a reaction will be spontaneous or not. For these participants, a negative ΔH indicates that a reaction will be spontaneous.

The reasons given by those who indicated that the statement was false varied. Only three lecturers and sixteen students gave acceptable reasons. The variety of reasons are given in table 1b below.

Table 1b. Reasons given for correct choice "False"

Reasons	No. of lecturers	No. of students
Acceptable 1. Spontaneity does not depend on ΔH only 2. Exothermic and endothermic reactions can be spontaneous and also non-spontaneous	2 1	0 16
Alternative ideas 1. Heat energy has to be applied to spontaneous reactions 2. Spontaneity depends on the nature of reactants and not on energy	1 0	1 2

To be able to identify more ideas from the participants, reasons given for choice "true" were classified. This classification appears in table 1c.

Table 1c. Reasons given for incorrect choice "True"

Reasons	No. of lecturers	No. of students
1. Exothermic reactions are spontaneous because they are accompanied by a release of energy	1	10
2. Because exothermic reactions do not need an external energy to make it happen	1	11
3. Exothermic reactions are accompanied by an increase in randomness	0	2
4. Perceivable changes to show that a reaction has taken place	0	2

It is evident from table 1c that ΔH is regarded as a criterion for determining spontaneity. The activation energy, which is particularly evident with endothermic reactions, is regarded as an opposing factor to a reaction occurring spontaneously.

Question 2

Spontaneous reactions may be fast or slow:

Table 2a. Number of participants that opted for "True" or "false"

* True		False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
6	43	2	7	1	4

The results in table 2a show that the majority of the participants got the answer correct. However, this good performance does not correspond well with the reasons given for the correct choice "true" in table 2b below.

Students often confuse the rate of a reaction with spontaneity. Spontaneous reactions can be fast or slow. If slow, the reaction has a high activation energy. If fast, the reaction has a low activation energy. Some reactions which are spontaneous can take many years to occur.

Slow reactions can be accelerated by adding a catalyst which offers the reaction a different mechanism with a lower activation energy.

Table 2b. Reasons given for correct choice "true"

Reasons	No. of lecturers	No. of students
Acceptable		
Spontaneity is independent of the rate of reaction	2	3
Alternative ideas		
1. Spontaneity depends on the nature of bonds between the reactants	2	15
2. Depends on the energy liberated by the system	0	2
3. Spontaneity depends on the rate of the reaction	1	1
4. Depends on the type of catalyst added	0	3
5. Depends on the energy needed to make it occur	0	3

Some lecturers and students believe that the nature of bonds between the reactants determines whether the reaction will be fast or slow. The strength of bonds in the reactants and products determines whether the reaction will be endothermic or exothermic. When weak bonds break to form strong bonds, energy is released, and the enthalpy of the products is lower than that of the reactants. Such a reaction is exothermic but not necessarily spontaneous.

One lecturer and three students (who opted for "false") indicated that spontaneous reactions were fast. Perhaps this idea emanates from the everyday use of spontaneity which often means rapid or fast.

Question 3

Spontaneous reactions occur because weak bonds in the reactants break and form strong bonds in the products:

Table 3a. Number of participants that opted for "True" or "False"

True		* False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
6	23	1	24	2	7

* Indicate the correct answer

This item is in effect a restatement of question 1. It refers again to exothermic reactions. Formation of strong bonds in the products from weak bonds in the reactants is accompanied by release of energy. However in endothermic reactions, strong bonds in the reactants break

to form weak bonds in the products.

Not surprisingly the pattern of responses is similar to the pattern in question 1.
The majority (6) of the lecturers and about half of the students (23) chose the incorrect answer which indicates that reactions are spontaneous when weak bonds in the reactants break and form strong bonds in the products. This simply means that exothermic reactions are spontaneous. About half the students chose the correct answer but the reasons behind their choice reflect a variety of alternative ideas (see table 3b). Only one student and one lecturer gave acceptable explanations.

Table 3b. Reasons given for correct choice "False"

Reasons	No. of lecturers	No. of students
Acceptable Criterion for spontaneity does not involve bond breaking and bond formation	1	1
Alternative ideas 1. Strong bonds can be replaced by weak bonds	0	6
2. Reactants at high energy have to release energy to the environment	0	4
3. It depends on the nature of the bond, i.e. ionic and covalent	0	2

This item again shows that some of the lecturers have difficulties concerning criteria for spontaneity. The predominant wrong idea again in effect is that exothermic reactions are spontaneous.

Question 4

Spontaneous reactions occur because the positive and negative charges of the reactants attract each other:

Table 4a. Number of participants that opted for "True" or "False"

True		* False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
2	23	6	23	1	8

The results in table 4a show that the majority of the lecturers and half of the students who responded to the question realised that the statement was incorrect. Probably from the students point of view it was just a matter of guess work, because in the reasoning section,

only seven students gave the correct reason. A variety of reasons was given by both the lecturers and students. Only the relevant and common ones are given in table 4b below. One lecturer and one student held a similar idea that spontaneity depends on the strength of the bonds as well as the electrostatic forces between reactants.

Table 4b. Reasons given for correct option "False"

Reasons	No. of lecturers	No. of students
Acceptable Spontaneous processes do not always involve attraction by charges (one student gave an example with an expanding gas)	2	7
Alternative ideas Spontancity depends on the strength of bonds and electrostatic forces between reactants	1	1

Two students continued to express the misconception that only exothermic reactions are spontaneous. "Spontaneous reactions occur when the energy of the reactants is higher than that of the products".

A common reason for the choice "true" was that ions in the reactants exert attractive forces on each other in order to form products. This idea was offered by one lecturer and nine students.

Question 5

The rusting of an iron-nail is spontaneous:

Table 5a. Number of participants that opted for "True" or "False"

* True		False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
6	30	1	18	2	6

The rusting of iron is spontaneous. There is no continuous work done to keep the reaction going. The process is a bit slow but it remains spontaneous.

The majority of the participants responded positively to this item as indicated in table 5a. The reasons given in table 5b however show that very few do actually understand the

criterion for spontaneity. Again, even in this item it becomes evident that two lecturers and some ten students believed that no activation energy or external factors were required to start the reaction. On the other hand, water and oxygen were regarded by some as external factors causing rusting, leading to the conclusion that the rusting process cannot be spontaneous. The idea that spontaneity is rate-dependent is also evident.

Table 5b Number of participants that opted for "True" or "False"

Reasons	No. of lecturers	No. of students
"True" reasons Acceptable Because the reaction occurs on its own	2	1
Alternative ideas 1. There is no external activation energy supplied	0	10
2. No catalyst is added	0	2
3. Because the reaction is slow	0	1
4. Rusting is a change that is irreversible	0	3
5. Process of rusting is continuous	0	1
6. Because the reaction is exothermic	1	0
7. Water and oxygen are external factors causing rusting	2	0
"False" Reasons 1. Reaction is slow	0	7
2. Water and oxygen are external factors causing rusting	0	7

Question 6

Non-spontaneous reactions can never occur:

Table 6a Responses to question 6 "True or False"

True		* False		No response	
Lecturers	Students	Lecturers	Students	Lecturers	Students
0	7	8	40	1	7

Non-spontaneous reactions can occur but work has to be done continuously to make them proceed.

The majority chose the correct answer but the reasons given for this choice revealed a variety of alternative ideas about possible means of making non-spontaneous reactions occur. Only four students and four lecturers gave the correct reason that a continuous supply of energy is essential. Two of these students supported this view by indicating a possible source of energy to be coupling a spontaneous reaction to a non-spontaneous one.

Some students (see table 6b) believe that adding a catalyst will make a reaction spontaneous. This is not so as a catalyst simply speeds up a spontaneous reaction by offering a different reaction mechanism with a lower activation energy. Once again spontaneity is associated with a kinetic rather than a thermodynamic meaning.

Table 6b Reasons given for correct option "false"

Reasons	No. of lecturers	No. of students
Acceptable		
1. Continuous work should be done on non-spontaneous reactions	4	2
2.Coupling spontaneous reactions to non-spontaneous ones	0	2
Alternative ideas		
1. Requires energy from outside to make it happen	1	5
2. Need activation energy to start a reaction	0	6
3. Need a catalyst	0	6
4. Reaction must be exothermic	1	1
5. Occurs when free energy of the system increases	0	1
6.Occurs when the free internal energy of the reactants is the same	0	1

Summary of the ideas identified in the analysis of section B Pre-questionnaire on "Spontaneity".

Some of the misunderstandings found to exist among both CEDS and lecturers are:

- confusion between rates of reactions and thermodynamic spontaneity
- change in enthalpy regarded as the only factor determining spontaneity
- failure to identify a slow reaction as spontaneous
- a catalyst is seen as something that can activate or initiate a non-spontaneous reaction.
- role of activation energy in reactio. s is not well understood

These ideas show that during lectures, students did not acquire the correct conceptual understanding of spontaneity in chemical and physical changes. Since some of the lecturers shared these misconceptions, it is not altogether surprising to find this outcome.

CHAPTER 5

ANALYSIS OF COLLEGE OF EDUCATION STUDENT INTERVIEWS

5.1 Introduction

Interviews were conducted with only ten college of education students. Six students came from a college in the Northern province while the other four were from Mpumalanga. These students volunteered through the encouragement of their lecturers. They were interviewed after they had done the topic on thermodynamics and written the post-questionnaire.

The procedure used in the interview process mostly involved semi-structured questions. The questions were based on live demonstrations and also on everyday phenomena. The three demonstrations were chosen because students were familiar with them. At the beginning of every interview session three live demonstrations were conducted by the researcher. Questions about the demonstrations served as the starting point for the interviews.

Description of demonstrations:

1. The first demonstration was about ammonium chloride dissolving in water. This is an endothermic change. A solution is formed.
2. The second was about water mixed with nitric acid. This is an exothermic reaction and a solution is formed.
3. The third was iron filings mixed with sulphur. This was heated to activate the reaction. This is an exothermic change.

In all the three demonstrations a chemical reaction did occur. All the reactions were spontaneous. The third demonstration was used as an example of a slow spontaneous reaction at room temperature which in an everyday sense would be taken to be non-spontaneous.

Students were asked to explain the observations they had experienced from the

demonstrations. In their explanations they had to decide whether a reaction had taken place or not. From the answers given by students, they were asked to explain further their understanding about chemical reactions using knowledge about entropy, energy changes, spontaneity and free energy. A question about attainment of thermal equilibrium and spontaneity was also asked. Students who were unable to express their ideas verbally were encouraged to write their responses on paper. The interview protocol was flexible in this regard.

5.2 Analysis of interview data

A method developed by Erickson (1979) on conceptual inventories was used to analyze interview transcripts. A conceptual inventory of ideas for each student interviewed was drawn up. At the end all student inventories were compared to identify broad common statements and ideas that were shared by many students.

5.2.A Chemical reactions

All the students (n = 10) indicated that a chemical reaction had occurred in demonstrations 1 and 2. Demonstration 3 was regarded by 9 out of 10 students, as a case where a reaction had not occurred. Different criteria were used to determine if a reaction had occurred or not (see table 1 below). The predominant ones were:

(i) the observation of an immediate change in temperature, experienced as either hotness or coldness when the reaction vessel is touched. Such a reaction was also regarded as spontaneous.

(ii) whether the reactants were homogeneous or heterogeneous mixtures in nature. Homogeneous here was used to describe reactants which were both aqueous liquids. When the reactants were solids, as in the case of sulphur powder and iron filings, the response was that no reaction took place because there was no solution or solvent.

Table 1. Criteria used to identify a chemical reaction in the three demonstrations.

Demonstration	Did the reaction occur or not	Criteria used: (i), (ii)	Frequency**
1	occurred	(i)	10
2	occurred	(i)	10
3	did not occur did not occur	(i) (ii)	5 5

** Frequency = number of times the idea was mentioned

Both criteria used were based on perceptual changes. A majority of students used criterion (i) which is acceptable but it means that the students will fail to identify a reaction that takes place without a noticeable temperature change. The following excerpts are examples of statements used indicating criterion (i) in demonstrations 1 and 2:

Sipho: 1 - 6 *(demonstration 1) There was a sudden decrease in the temperature on the test tube. Now meaning that heat has been removed from the surrounding into the system. That is why the test tube became cooler.*

I: *What did you observe in experiment 2?*

Sipho: *(demonstration 2). That was purely an exothermic reaction. That is heat moving away from the system. Liberated heat is used to feel the rise in temperature in the test tube. Meaning that heat had to move away from the system to the surrounding.*

Reub: 63 - 66 *(demonstration 1) The ammonium chloride dissolved in water and the reaction is endothermic since it absorbed heat from the surroundings. The test tube is cold.*

Reub: *(demonstration 2). A reaction occurred because the test tube is warm when the water mixes with nitric acid.*

Meshack: 125 - 128 *(demonstration 1). I noticed a temperature change. It decreased...*
(demonstration 2). The temperature of the new solution is a bit warm.

Only one student indicated that in demonstration 3 the reaction did occur and was spontaneous and also endothermic. He said that the reaction was very slow at room temperature, and hence it needed to be activated by heating. All other students (9) said that the reaction was non-spontaneous. They suggested that it should be heated or a catalyst added to make it spontaneous.

About half the students used criterion (i) and half used criterion (ii) in demonstration 3. (See table 1 above). The use of criterion (ii) is completely wrong. Perceptual observations are not always applicable to all the chemistry situations. For example:

Criterion (i):

Meshack: 137 - 140

I: *What about the iron filings and sulphur powder?*

Mes: *This one is not spontaneous.*

I: *How will you make it spontaneous?*

Mes: *By applying heat.*

Sophie: 58 - 60

I: *What did you observe in experiment 3?*

Sop: *No reaction has taken place.*

I: *Why?*

Sop: *Because the temperature remained the same. This is a mixture and not a solution.*

One student used criteria (i) and (ii) but finally decided that criterion (ii) was suitable for deciding if in demonstration 3 there had been a reaction.

There was only one student who used a different criterion. He indicated that in demonstration 3 no reaction was observed because there was no solvent to weaken the forces that bind a particular material. This further supports the idea that for a reaction to occur at least one reactant should be a solution or liquid. The liquid is perhaps considered to be a solvent for dissolving the solid reactant, eg in the case of ammonium chloride dissolving in water. A similar idea about the required presence of a solvent (water) was

reported by Ribeiro, et al (1990), where one student said that reactant's bonds were broken and new bonds were formed because the substances dissolved in water.

Some students said that the first two demonstrations were spontaneous whilst the third one was non-spontaneous because only the first two occurred rapidly or immediately. One student further said that because we had to heat the mixture of sulphur powder and iron filings, the reaction was non-spontaneous. According to this student whenever substances are heated to initiate the reaction it means the reaction is non-spontaneous. This idea was also common in the questionnaires. This is incorrect. Some reactions occur very slowly because of high activation energy barriers. Energy is then needed to initiate these reactions. Thereafter the reaction may continue without any further addition of energy.

Students ideas about reactions were further revealed when they were asked to answer the following questions about reactions:

1. What are chemical reactions?

The majority of the students said that they are processes whereby reactants (elements) mix to form compounds.

Gregory: 123 - 124

I: *From your view point what is a reaction?*

G: *It is a process whereby the reactants mix to form a compound. The components of a compound cannot be easily separated.*

Reuben: 85 - 86

R: *Chemical reaction is when chemicals, for instance ...when elements mix to form compounds or when compounds and compounds are put together that is a chemical reaction.*

The above explanation is partially correct, but it would be expected that at the college level students would use the idea that in a chemical reaction substances (reactants) react to form

new substances which are different in properties from the original reactants.

Some students said that a chemical reaction is an encounter between two reactants in which there is donation or transfer of electrons. These students gave their description on the atomic level. Ogude (1991) also found that students used the atomic description in explaining their understanding about electrochemical reactions. Though it is expected of them to be able to operate at both the macro and micro level, their explanations indicate that their understanding is very incomplete. Though they possess knowledge about atomic particles, they are often not aware when to use such knowledge, so they end up using it indiscriminately.

Sipho: 12 - 16

S: *... let me say that it is a heterogeneous mixture of sulphur and iron filings.*

I: *Is there a reaction?*

S: *A reaction....No*

I: *From your point of view what is a reaction?*

S: *Actually it should be an encounter between two reactants. We should have two reactants encountering one another, whether as an attack or donation of electrons or transfer of electrons.*

From these statements, it is obvious that there is a serious lack of conceptual understanding of chemical reactions among some college of education students.

2. Why do chemical reactions occur?

There were three main categories of answers which were used by students. These are summarised approximately here as:

(i) the nature of reactants, (Total frequency = 5)

subcriteria	frequency
polarity of substances	2
reactants and products must be solutions and not heterogeneous mixtures	3

Example:

Reuben:(90) *I think they are of the same nature. For example, they are polar. If they are different, we may not get a chemical reaction. e.g. paraffin and water cannot mix because they are not of the same nature. One is polar and the other is non-polar. When you add water in potassium permanganate, it dissolves, indicating a reaction because they are all polar substances.*

(ii) reactants possess an energy or force (repulsive or attractive) that makes them react. (Total frequency = 7)

subcriteria	frequency
reactants possess an energy which makes them react	1
reactants possess a force that is attractive or repulsive to make them react	1
reactants absorb energy causing a reaction to occur	4
ΔH is the energy the reactants had before the reaction. This energy is released and decreases during the reaction. It must be negative for a reaction to take place	1

(iii) reactants either donate or transfer electrons (Total frequency = 8)

subcriteria	frequency
donate or transfer of electrons	5
reactants formed ions	1
electronegativities of atoms	2

The choices of criteria (ii) and (iii) indicate that students were starting to think in microscopic terms about the reaction. One would expect more than seven students at this level to talk about energy changes, but only one student used energy changes, in a partially acceptable way as exemplified by the following excerpt

Johannes: 206 - 207

I: *Why do chemical reactions occur?*

J: *It occurs when the reactants have energy. Sometimes the energy of the reactants can be so low in such a case the reaction cannot take place rapidly. It means that the activation energy should be added. For a reaction to take place there should be energy available.*

Another student tried to explain the occurrence of reactions in terms of energy transfer but was confused about the kind of energy and the source of it. According to him the energy available comes from the transfer of electrons from one substance to another. His final decision was that reactions occur because of the transfer of electrons. For example:

Lawrence: 208 - 211

L: *Two substances, these reactants are different in energy so some they transfer their electrons to one another to form a reaction. That means energy causes reactants to occur so that we ultimately have a reaction.*

I: *How does the energy you are talking about cause a reaction to occur?*

L: *These happen because the substances reacting are different, some have the ability to accept. So if a substance can donate electrons the other one will accept them and as such there will be a reaction.*

I: *What about the energy you spoke about?*

L: *The energy I am talking about I think it is just the transfer of electrons from one substance to another.*

More ideas about chemical energy are discussed under the section on spontaneity and free energy.

5.2.B Entropy

1. What is entropy?

The interviews revealed some confusion among students with respect to the nature of entropy. Only three students gave a correct explanation that entropy is a measure of the disorder of the system. Seven students gave the explanation that entropy equals the disorder of a system. There is probably some confusion about the relationship between entropy and disorder.

46. Sipho: Entropy is just a change in disorder of a system.

Entropy is sometimes equated with disorder, for example:

74. *Sophie:* *If the enthalpy and the disorder are positive and .... the reaction will be spontaneous.*

76. *Sophie:* *There is an increase in disorder in a spontaneous reaction. In a non-spontaneous reaction there is no disorder. Then the free energy will be positive.*

150. *Gregory:* *The state in which substances change from an orderly state to a disordered state.*

351. *Ronnie:* *When you are talking about entropy, you are talking about the disorder of a system.*

Some students (3), who responded positively to the question on the increase of entropy when a gas is heated at constant volume, indicated that an increase in entropy caused more disorder.

The problem with the students was equating entropy with disorder. The idea that we use entropy to measure the degree of the disorder of a system is not clear from the statements given in the interviews.

The idea that change in entropy should be positive for a reaction to occur does exist (perhaps from memorisation of the second law of thermodynamics). However the reason why entropy has to be positive is not clear from their explanations as shown by the excerpt below:

25. *I:* *What does delta S positive mean?*

G: *It means that work has been done on the system.*

I: *What type of work?*

G: *I mean like the case in melting. Work has been done to change it from one phase to another.*

2. What is the relationship between entropy, randomness and movement of particles?

In order to identify student's conceptions of the relationship between entropy and randomness the following question was asked:

"Suppose we have a mole of hydrogen gas in a 10 litre container at 25°C. We then heat it to 50°C at a constant volume. What will happen to the entropy of the gas?"

All students with the exception of one, said that the entropy will increase. There were various reasons given for this correct answer. The reasons given indicate that students have conceptual difficulties regarding why entropy increases when the temperature of a gas is increased at constant volume. The reasons given have been categorised as follows:

(i) because the increase in kinetic energy leads to an increase in the speed of particles and randomness and increased or more collisions of the gas particles [4 students]
(ii) because the system absorbed heat [2 students]
(iii) because the system caused more disorder [3 students].
Clearly the students classified under category (i) saw collisions as a cause of disorder and hence greater frequency of collisions lead to greater disorder. Students therefore experienced difficulties in understanding what is meant by "randomness".

Scientifically, entropy is related to the number of ways in which a system can store its total energy, that is the division of energy among particles. When a gas is heated at constant volume, there is an increase in the amount of energy in the system. As more energy is supplied, the number of ways that the gas particles can absorb energy increases, and so the entropy of the gas increases. This change has nothing to do with positional or spatial randomness of the gas particles.

Perhaps the notion of randomness that exists among many of the students comes from the very simplified explanations in some general chemistry textbooks. These books are not entirely wrong but they have oversimplified the definition of entropy. It is therefore

important to make it clear to the students that the increase in entropy is more related to the randomness of distributing or storing energy in different ways. The limitation in the definition of entropy (in many general chemistry books) should be made clear to students.

One student said that entropy will not increase because entropy change requires the volume to change so that the molecules of gas are free to move. This student is very much aware that increase in spatial randomness is a factor of volume change.

357. *Ronnie:* *.....the entropy will not change in this case since it does not have a role here. For the entropy to change it means the volume must change so that molecules are free to move... only internal energy will be increased.... This will not affect the randomness of the particles since the volume is constant. Entropy will also be constant.*

3. Entropy and chemical change

Many students could not give the correct reason why entropy is important in chemical reactions. Students did indicate that the change in entropy should be positive in order for a chemical reaction to occur. Difficulties associated with this section may explain the difficulties experienced by students in relating thermal equilibrium to entropy.

A chemical reaction is accompanied by changes in energy and entropy. A reaction can only occur if the change in total entropy of both the system and the surroundings is positive.

Only five (5) students responded to the question about the role of entropy in chemical change. All of them said that for a reaction to occur, the overall change in entropy must be positive but the reasons given differed from those of the scientific community. Their responses have been categorised as follows:

(i) entropy tells us about the nature of reactants - whether they are solids, liquids or gases [2 students]

(ii) entropy tell us about the nature of the disorder of the system [2 students]

(iii) entropy shows that work has been done on the system [1 student].

One student used both criteria (ii) and (iii).

Only one student among the five based his understanding of entropy in chemical reactions on the second law of thermodynamics and then described his understanding as shown by the following transcript section:

46. *Sipho:* *.... I believe entropy has an effect on the nature of the reactants as we have said that the spontaneous reaction occur without any other external help. Now the nature of the reactants, as liquid or gas, because they are having an entropy, may help towards improving spontaneity.*

47. *I:* *Do you still have something more to say?*

48. *Sipho:* *Yes, According to the second law of thermodynamics which talks about the change in the entropy of the surroundings plus the change in the entropy of the system must always be greater than zero..... If I heat water, for it to become a gas, I am changing from liquid to gas. If I heat water, the liquid is getting heat from the surrounding and the surrounding is losing heat such that the number of moles of vapour as the water is becoming vapour now, it gets into the air. The system gains heat so as to increase its kinetic energy and thus increasing its disorder, that is entropy. So an increase in disorder leads to an increase in spontaneity.*

The explanations given here indicate that the student has a vague understanding of the second law of thermodynamics.

4. Entropy and thermal equilibrium

All students said that when two bodies at different temperatures are brought into contact with one another, there will be a transfer of heat energy from the body at a higher temperature to the body at a lower temperature. When they were asked to explain why the

transfer followed the direction they described, many of the students could not describe it in terms of change in the direction of maximum entropy. When ever there is thermal energy transfer, the energy flows in the direction that produces an overall increase in entropy and stops when entropy is at a maximum. This is the point when thermal equilibrium is reached. Students rather based their explanations on collision theory and movement of particles, as shown in the following excerpts.

108. *S2:* *Because A is hotter than B, there will be a change in temperature between A and B. A will decrease and B will increase in temperature until they all have the same level of temperature.*

I: *Is it possible that heat energy can be transferred from body B to A?*

S2: *Not possible.*

I: *Why?*

S2: *Because there is less kinetic energy in the cold body. It will be the heat that will travel from the hot body and not from the cold body.*

Three students believed that during thermal energy transfer, the temperatures of the two bodies should be added, that is 20°C + 10°C = 30°C. In fact, at the end the two bodies will be at the same temperature of 15°C. A similar observation has been reported by Driver et al (1985).

94. *Reuben:* *If for instance when they come together, the temperature must be balanced. I think body A since it is 20°C and body B at 10°C , they will have to share the temperature. That is body B will get some few heat or energy from body A so that they will reach equilibrium and hence have equal temperatures.*

186. *Meshack:* *There will be negative numbers. 20°C - 30°C = -10°C.*

365. *Ronnie:* *(Body A at 40°C and body B at 20°C)*
Heat will eventually flow from body A to body B. They will eventually reach an equilibrium state where they will have equal temperatures. If it does not lose anything we are going to have the

system having 60°C. .... We are talking about the sum of the temperatures. The combination of the two temperatures.

The problem of failing to differentiate between temperature and energy is evident. Three students kept on using temperature and energy interchangeably throughout the interviews. There is a belief that temperature is like a substance, it can be transferred from one body to another. Similar findings have been reported by Driver et al(1985). The following excerpts are examples:

332. J: *There will be heat transformations. The energy or the temperature of body A will be transferred to that of body B and the temperature of body B will be transferred to body A because of the concept that says energy can never be created or destroyed but can be changed from one form to another. It means they will be having the same energy or temperature.*

334. J: *I should think the body with the lower energy it has to retain the higher energy of that other substance, so that they ultimately will have equal energy.*

340. L: *This is a matter of heat transformations. They will try to maintain the temperature of each other. In this case another one cannot be left at a higher temperature than the other one. They try to balance their heat energy.*

Statements 334 and 340 indicate that the students are not sure of what is equalised when the two bodies come into contact, heat energy or temperature? In fact the energy contents of the two bodies will not be equal, only their average kinetic energy will be equal at the point when they reach thermal equilibrium.

5. What are the factors affecting entropy?

Entropy depends on the temperature, type and amount of the substance, (volume in the case of gases) and the state of the substance or system. The answers given by students show that factors affecting entropy were vaguely understood or not known at all. Students said that

the entropy of a gas will increase when the volume is increased, but got confused about exactly how the volume affects entropy increase. Most (seven) students interviewed believed that the entropy increases because there is more space for the particles of the gas to move about and collide. (In fact more space means less frequent collisions). More collisions meant an increase in entropy for these students. Perhaps this confusion is brought about by some misunderstanding about collisions causing disorder.

Temperature was not directly mentioned by students as a factor affecting entropy, but was mentioned when they tried to solve other problems related to entropy change.
When students were asked to describe what happens to entropy as the temperature of the gas is increased, 8 students said that the entropy will also increase. The reasons given by four students for the increase in entropy were that particles of gas gained internal energy, became more excited and hence more disordered.

166. G: I think the entropy of the gas will increase due to the fact that as more of the gas molecules are heated, the average kinetic energy of the molecules increases, resulting in more and more disorderliness of the hydrogen gas.

120. Reu: It will increase since the particles of the gas will gain energy and become more excited and there will be more disorder in the container and hence the entropy will increase.

14. G: Because the increase in temperature increases the kinetic energy of the particles, there will be more disorder when the temperature is increased.

48. G: The average kinetic energy will increase so that particles will have a higher speed. The higher speed will increase the entropy.

148: X: The molecules of the gas will start to move and squash against one another resulting in more collisions thus resulting in higher entropy.

The size of the molecules of the substance was another factor mentioned. There are two aspects of the molecular structure that affect the value of the substance's entropy:

1. The degree to which the movement of the atoms and molecules in the structure is

restricted; the less restricted the movement, the greater the entropy.
2. The mass of the atoms and molecules which are moving; the greater the mass the greater the entropy.

When students were asked to choose the substance which will have the greater entropy between one mole of carbon dioxide and propane gases, the size of the molecules became the centre of their answers.

All the (10) students first wrote the molecular structures of the two gases. Then their arguments were based on the drawn structures. Two criteria used were:

(i) carbon dioxide molecules are small, with fewer atoms, and therefore carbon dioxide molecules have greater entropy because molecules can expand and move more rapidly to occupy more space thus increasing randomness and the number of collisions. Propane molecules will be compressed with no free movement of particles because they are large and have little space to move in.
[Idea held by 7 students]

(ii) propane has a greater entropy because its molecule has more atoms than carbon dioxide. More atoms leads to increased movement of particles.
[Idea held by 3 students]

One student showed his strong belief in criterion (ii) by adding that the density of propane gas is higher, which contributed towards its greater entropy.

Excerpts of students using criterion (i):

172. Greg: *I think carbon dioxide will have the greatest entropy because it is a small molecule as compared to propane, which is a large molecule. The carbon dioxide molecule will keep on rising.*

325. Johannes: *It is carbon dioxide. We are concerned with the number of carbon atoms in the compound. Propane has more number of carbon atoms again it is a bigger structure than carbon dioxide. At standard temperature and pressure conditions, carbon dioxide will have more entropy than propane because of its size.*

I: *How does the size of the molecule affect the entropy?*

327. *Johannes:* *In fact when ever we are increasing entropy we are causing a disorder in a system.*

36. *Gregory:* *A carbon dioxide molecule has got three atoms and propane has got eleven atoms. So if we put carbon dioxide in a test tube it will have a larger space to move than particles of propane. Particles of propane will be compressed as compared to particles of carbon dioxide.*

37. *I:* *Can you summarise your response?*

38. *Gregory:* *Carbon dioxide particles will have a bigger space to move, so the randomness of the particles will be greater than that of propane.*

40. *Gregory:* *The movement of the particles of carbon dioxide will be very much disorganised than in propane, because propane particles are many, so they have little space to move in.*

Excerpts of students using criterion (ii):

94. *S2:* *Because the compound is larger than carbon dioxide.*
When there is disorder, it will occupy large space or volume.

116. *Reuben:* *Because propane has more carbon bonded to many hydrogens than carbon dioxide.*

117. *I:* *How does the number of atoms affect the entropy?*

118. *Reuben:* *The movement of particles in the propane is more than in carbon dioxide.*

In both criteria, the students perceived the movement of particles to be important in taking decisions about the value of the entropy. It seems the movement they talk about here is not related to the movement of atoms in the molecule (that is the rotational and vibrational movement within the molecular structure) but to the movement of the gas molecules within a container. This kind of thinking may underlie the confusion between entropy and kinetic energy.

6. Why is the entropy of solids lower than of liquids and gases?

149. X: because the velocity of the molecules decreased.

The above statement further indicates the difficulties the students are facing in understanding the factors affecting entropy. Three students said that the entropy of solids is lower than that of liquids and gases but could not give the correct reason which is based on the restricted movement of atoms within the structure of a solid. One student said that he was not sure why entropy of gases is higher than of liquids and solids, but just knew it to be like that.

5.2.C Spontaneity and free energy

1. Criteria used to determine whether a process is spontaneous or not

There were all sorts of explanations given for these questions. The answers have been classified according to the criteria below. Some students used more than one criterion.

(a) Spontaneous reactions occur without any external interference [students = 3].
This idea probably is used because of the influence of the daily use of the word, spontaneous. Generally a process is spontaneous if it is seen to be occurring without interference.
This criterion was used mainly in the classification of the first two demonstrations.
Example;

18. Sipho: A spontaneous reaction .... I mean by the word spontaneous we refer to the capability of a particular reaction to take part without the help of any external factors like heat; ....It means it takes place on itself without applications of external factors.

This idea was also identified in the pre- and post questionnaires among many students. Similar results were also reported by Ribeiro et al (1990).

(b) Slow reactions cannot be spontaneous because spontaneous reactions occur rapidly [students = 5]

Most of the students who used this criterion said that iron filings cannot react with sulphur spontaneously because the reaction was very slow at room temperature. Students based their argument on the perceptual observation of the first two demonstrations, which occurred instantaneously. Perhaps with this criterion also students based their decision on the everyday use of the word spontaneous which can mean rapidly or very fast.

(c) No activation energy is required in spontaneous reactions [students = 3]

This idea supports the above idea that spontaneous reactions occur without external interference. More than half of the students who said that "it occurs without external interference" said that no activation energy is required. Whenever a reaction was initiated by giving activation energy, especially by heating, the process was regarded as a non-spontaneous one.

20. *Sipho: Non-spontaneous reactions are those reactions that cannot take place by themselves. They need something to help initiate the reaction.*

The reaction between sulphur powder and iron filings was regarded by many students as non-spontaneous. When they were asked to suggest a way of making it spontaneous, they said that it needed activation energy in the form of heat to make it spontaneous. In fact this is a very slow reaction at room temperature, and we have to activate it by heating.

For example:

56. *Gregory: I do not think the reaction between sulphur powder and iron filings will occur because this is a non-spontaneous reaction. ....May be if we can heat it will start reacting.*

(d) Only exothermic reactions are spontaneous [students = 3]

There were many supporting statements to this idea, e.g "reactions are spontaneous when enthalpy change is negative" and "reactions are spontaneous when the sum of the enthalpies of the reactants and products is negative".

For example:

14. Given: I think one will look at ΔH of reactant A and ΔH of reactant B. If their sum is positive, I think the reaction is non-spontaneous.

According to students who hold this idea, reactions which are endothermic cannot be spontaneous. One factor which fosters students strong belief in this notion is the perceived increase in temperature when an exothermic reaction takes place. Many of the endothermic reactions need activation energy to initiate the reaction. Such a process is regarded as non-spontaneous just because the process has been activated and again because the change in enthalpy was positive. The conceptions given here are associated with the be. . that spontaneous reactions do not need an external interference. For students who hold this idea it might be difficult for them to appreciate the fact that certain endothermic reactions occur spontaneously at room temperature and also that certain exothermic reactions are non-spontaneous. This idea was also reported by Johnstone et al (1977) in their study with sixth form Scottish students and Ribeiro et al (1990) with fourth year undergraduate chemistry students.

In scientific terms, a process occurs spontaneously because it has a thermodynamic tendency to occur. The process can be fast or slow. If we can see a reaction happening, we can say it is spontaneous, but if we do not see anything happening, the reaction may or may not be spontaneous. The apparent lack of reaction may be due to an energy barrier. The process may require activation energy to overcome the energy barrier. Once this is achieved, it may no longer be necessary to transfer energy to the reactants. The reaction just proceeds on its own to the end. In a non-spontaneous reaction, work must be done on the reactants at all times until the reaction reaches the end. This is different to the role of activation energy. Scientifically, spontaneity means that the free energy change of the reaction is negative.

Only two students were able to use the above scientifically acceptable explanation. They mentioned the natural tendency to occur irrespective of the rate of the reaction.
All the four criteria identified here as (a) - (d) were common also in the questionnaire responses.

2. What makes processes spontaneous?

Many students could not explain it in terms of the change in free energy, unless they were asked to use free energy in their explanations. Some of the students did mention that there is an energy change in the process, but they did not refer to free energy change in their explanations. They seemed confused as to what type of energy change was involved.

The four common criteria that the students used were:

1. Spontaneous reactions occur because of an increase in the number of moles of the reactants. The increase in the number of moles results in an increase in volume and greater number of collisions and randomness which lead to a reaction being spontaneous [students = 2].
2. Spontaneous reactions occur because of an increase in kinetic energy of the molecules resulting in an increase in the number of collisions of molecules [students = 5].
3. Reactions occur spontaneously because reactants have a higher entropy [student = 1].
4. Reactions occur spontaneously when the sum of the enthalpies and disorder are negative [students = 2].

Students who used free energy change in their explanations, (only when they were asked to do so) showed a superficial understanding of the concept. The following explanations of free energy change were used by students:

1. It is the energy taken out or lost by the system during a reaction [students = 6]. Three students among the six said that free energy was the energy lost during the reaction and it will be replaced with thermal or heat energy.
2. Free energy is the internal energy that makes substances react [students = 2].
3. It is the energy that has not been used to cause the reaction to occur [students = 2].
4. It is the energy that causes disorder of a system [student = 1].

Only two students used the correct criterion that the sign of the change in free energy determines if the reaction will be spontaneous or not. When change in free energy is negative, the reaction is spontaneous.

Some examples of the student's statements are:

155. *I:* *What do you know about free energy?*

156. *X:* *It is a Gibbs function which is used in calculating energy in voltaic cells.*

157. *I:* *What is the role played by free energy in chemical reactions?*

158. *X:* *It is used to make possible the reaction to take place.*

159. *I:* *How?*

160. *X:* *I think I have done a mistake.*

161. *I:* *Where have you done a mistake?*

162. *X:* *It is the energy which was used in the whole system.*

2. *Given:* *It (free energy) determines whether the body can undergo a spontaneous reaction or not. I think if free energy is very low or lost, the body would need some other energy.*

3. *I:* *What other energy are you speaking about?*

4. *Given:* *I think it is heat energy.... also thermal energy.*

This student (Given) used criterion 1. Misconceptions relating to heat, temperature and energy were also revealed. Given used "heat" as if it were a substance possessed by an object.

When Given was asked to explain the effect of temperature on free energy, he said that free energy is affected by the heat content of a substance but did not know how it affects it. Probably this student has a poor conception of heat energy at the microscopic level.

50. *Sipho:* *Actually, what I do believe, it is not only the entropy changes that can declare that a reaction will be spontaneous, it also depends on a number of things....temperature...Hence we need to introduce another aspect of determining whether a reaction will be spontaneous or not. That aspect is known as free energy change. The free energy change according to the relationship as determined by this equation* $\Delta G = \Delta H - T\Delta S$.

51. *I:* *Explain this equation to me.*

52. *Sipho:* *In other words according to this free energy change, we want to look as to what energy changes are happening within the system as heat is*

applied....For the reaction to be spontaneous, change in free energy should be less than zero. This depends on the enthalpy change and the entropy change together with temperature change.

Students understanding of the relationship between different terms in the equation $\Delta G = \Delta H - T\Delta S$ in determining the direction of spontaneity was also tested. Students were able to give the correct equation for calculating free energy change, but when asked to give a qualitative explanation of the equation, the majority of the students showed a vague understanding of the relationship. Only two students gave the correct interpretation of the equation. These two students explained it in terms of the effect of changing ΔH and ΔS on free energy and how free energy depends on temperature. The term, $T\Delta S$ was interpreted as an energy term having something to do with disorder. Therefore, it was not difficult for these two students to see that ΔH and ΔS were not the only factors responsible for determining the direction of spontaneity.

It seems students were familiar with calculating free energy change using the formula without understanding the conceptual relationship between the different terms in the equation. This difficulty is shown by the following examples;

228. *J:* *T is the symbol for temperature, change in S is the measure of the order of the system, change in H is the energy of the reactants and G is the energy of the whole system.*

158. *G:* *ΔG stands for change in free energy, ΔH stands for change in enthalpy and T is a constant temperature and ΔS stands for change in entropy.*
If the temperature is constant, only the values of G, H and S change....If the enthalpy increases to positive value, meanwhile the entropy remain unchanged or constant. This can make delta G attain a positive value. Which means the reaction will be non-spontaneous.

51. *I:* *Sipho, explain the equation to me.*

52. *Sipho:* *Ja, in other words, according to these free energy change, we want to look as to what energy changes are happening within the system,....hence we could determine whether the reaction will be spontaneous or not. For it to be spontaneous, ΔG should be less than zero. This depend on the enthalpy*

change and the entropy change together with the temperature change.....Suppose I am having both enthalpy and disorder (he meant entropy) as negative, ... now I will have to look at the relationships. If my ΔH is negative and the entropy change is negative, it will give me a positive value such that we should get a difference that is bigger and that is we should have a negative for spontaneous processes, the temperature must have high values. Not only high values of temperature, but it should be values which will account for not having the reaction at equilibrium.

These explanations are in effect repeating the equation in words.

The student's understanding of the conceptual relationship between the different terms in the equation, $\Delta G = \Delta H - T\Delta S$ was poor. Similar results, where students could use the mathematical equation in problem-solving but failed to understand the conceptual relationship between the different terms in the equation, were also reported by Granville (1985) and Ribeiro et al (1990).

3. What are the factors affecting spontaneity?

Table 3. Students answers to factors affecting spontaneity

Answer categories	frequency **
concentration and the number of moles of reactants	2
heat and kinetic energy change (including increased collisions)	7
change in enthalpy, entropy and the temperature at which the reaction is taking place	2
entropy change only	3
temperature	3
free energy change only	3
enthalpy change only	2
polarity and electronegativity of reactants	2

** frequency = the number of occasions the statement was mentioned by different students.

From table 3, it is clear that the majority of the students does not have a good understanding of the factors affecting spontaneity. Most of the factors mentioned here were the same as those given for entropy. Again kinetic energy (movement of particles) is regarded as the most important factor affecting spontaneity. This is probably due to the idea that is displayed by many students that an increase in the movement and collision of

particles leads to an increase in spontaneity. Collision theory seems to be the main theory used by students in determining whether a process will be spontaneous or not.

Those students who mentioned change in enthalpy and change in entropy separately, were not completely wrong but they missed the fact that the two factors could not determine the direction of spontaneous change individually.

No student mentioned the fact that non-spontaneous reactions cannot proceed on their own, but can be made to occur by a sustained input of energy. Work must be performed to make the non-spontaneous reaction occur. This can be achieved by coupling non-spontaneous reactions to spontaneous ones. The free energy of the spontaneous reaction is used to do work in a non-spontaneous reaction.

4. What can you do to make a non-spontaneous reaction occur?

Table 4. List of things that can be done to make a non-spontaneous reaction occur

Answer Categories	frequency
adding activation energy to initiate a reaction	2
adding a catalyst	5
only adding heat energy to activate the reaction	7
by increasing temperature and disorderliness	1
by increasing temperature and enthalpy	1

The responses in table 4 again indicate the conceptual difficulties regarding factors that affect spontaneity and the rates of reactions. For example, adding a catalyst was seen by the majority of the students as a good method of making a non-spontaneous reaction occur. In fact a catalyst is only used to speed up the reaction. It has nothing to do with spontaneity. Again many students did not make a distinction between activation energy and chemical energy change of the reaction. They believed that a reaction was not spontaneous because activation energy was given. Whenever a reaction was initiated by heating, i

309. *I:* *How can you make non-spontaneous reactions to be spontaneous?*

310. *L:* *I will increcse the temperature or enthalpy. There will be more value here (points to the equation he has written - ΔH - $T\Delta S$), therefore making the delta G negative.*

Adding a catalyst was the second widely mentioned statement. The following excerpt exemplifies this:

28. *Sipho:* *A non-spontaneous reaction to become spontaneous.....we can try to provide some heat in order to initiate the reaction....that is I can heat a test tube and the reaction may now start or show up to be taking place or I may put in a catalyst so as to try to minimise the activation energy, so that they start to react together.*

62. *S2:* *Other solutions occur spontaneously and the others need a catalyst in order to react with each other.*

70. *S2:* *The non-spontaneous reaction need a catalyst to start a reaction.*

106. *S2:* *By using a catalyst or by increasing the concentration of the reactants.*

203. *J:* *To let sulphur react with iron filings completely, I think a catalyst should be added even water. A catalyst or heat. This experiment need a catalyst to become a homogeneous mixture....then it will be a spontaneous one.*

The fact that students saw a catalyst as something that will make a reaction occur again indicates the existence of confusion between factors affecting reaction rates (kinetics) and spontaneity (thermodynamics).

5.3 Inventory of students' ideas and areas of conceptual difficulties

Common ideas pulled from the above interview analyses are summarised below to form an inventory of ideas and areas of conceptual difficulties.

5.3.A Chemical reactions

1. Observational criteria:
    (a) there should be an observable overall increase in temperature of the reaction mixture;
    (b) energy in the form of heat should be given off to the surroundings.
2. Micro-explanation criteria:
    (a) there should be an attractive force that makes elements mix and react in order to form compounds;
    (b) reactants possess energy which make them react;
    (c) the reactants and products must be solutions and not heterogeneous mixtures (eg; iron filings and sulphur powder);
    (d) there should be a transfer of electrons between the reactants;

Generally students believed that a chemical reaction occurred when they were able to see or feel some changes, eg, temperature increase or decrease. Their conceptions were mainly based on perceptions rather than on microscopic level events. Though there were students who gave descriptions on the microlevel, they revealed lack of correct knowledge, for example, the use of criteria 2a.

The idea that there should be an energy change in the process does exist among some students, but it is vaguely understood. This clearly contributes profoundly towards the difficulties they have in understanding the conditions necessary for reactions to occur.

5.3.B Entropy and disorder

1. Nature of entropy:
    (a) entropy equals disorder or is the same as disorder;
    (b) disorderliness (meaning entropy) makes it possible for compounds to dissociate;
    (c) an increase in entropy is the cause for the increase in the disorder of the particles.

2. The relationship between entropy, randomness and movement of particles:
   (a) when kinetic energy of the particles increases, their randomness increases and thus entropy increases (an increase in the speed of molecules leads to an increase in entropy);
   (b) when the temperature of a gas is increased the entropy also increases because particles gain internal energy, become more excited and more disordered;
   (c) as the temperature is increased the entropy of a gas is increased because of the increased movement of particles which results in more collisions and more disorder.

The difficulty the students revealed here is that they relate movement of particles (kinetic energy) with frequency of collisions and randomness. Low frequency of collisions relates to little and slow movement and high frequency of collisions to more and faster movement. Increase in frequency of collisions and faster movement are associated with an increase in entropy.

3. The role of entropy in chemical reactions:
   (a) reactions occur rapidly because reactants have a higher entropy.

Students showed very little or no understanding of the role of entropy in both chemical and thermal processes. Idea (a) confirms the existence of conceptual confusion concerning reaction kinetics and thermodynamics.

4. Factors affecting entropy:
   (a) a small molecule has a greater entropy because it can move more rapidly than large molecules. More rapid movements increase the randomness of molecules and the frequency of collisions.

5.3.C Spontaneity and free energy

1. Descriptions of spontaneity:
   (a) spontaneous reactions happen without any external interference;
   (b) no activation energy is required in spontaneous reactions;
   (c) only exothermic reactions are spontaneous. This leads to an incorrect idea

that all endothermic reactions are non-spontaneous;

(d) spontaneous reactions occur due to an increase in kinetic energy of the molecules which results in an increase in the frequency of collisions of molecules;

(e) the increase in the amount of reactants will result in an increase in volume and more frequent collisions and randomness which lead to a reaction being spontaneous;

(f) reactions occur spontaneously because reactants have a higher entropy;

(g) reaction will be spontaneous when the sum of the enthalpies of the reactants is negative;

(h) spontaneous reactions occur because of the high concentration of reactants;

(i) slow reactions cannot be spontaneous;

(j) spontaneous reactions occur rapidly.

2. Non-spontaneous reactions can be made to occur by:

(a) adding energy to initiate them;

(b) heating the reactants to activate the reaction;

(c) increasing the concentration of reactants;

(d) adding a catalyst.

3. Free energy:

(a) free energy is equated with heat or thermal energy;

(b) free energy is the internal energy that makes substances react;

(c) it is the energy taken out by the system;

(d) energy which has not been used to cause the reaction.

4. Spontaneity and thermal equilibrium:

The relationship between these two concepts is not understood by students.

(a) Students could not explain why thermal equilibrium was established. They could not explain it in terms of the increase in the overall entropy of the system and surroundings up to a maximum point.

5.4 Concluding remarks

These interviews of college students revealed a number of erroneous ideas about the concepts of entropy, free energy and spontaneity. Some of these ideas have been identified by other researchers in other countries with different types of interviewees (Johnstone, 1977; Driver et al, 1984; Granville, 1985; Ribeiro et al, 1990 and Ribeiro, 1992). The interviews confirm many of the findings from the questionnaires including the general observation that most students failed to learn meaningfully from the instruction they experienced on thermodynamics.

CHAPTER 6

DISCUSSION OF RESULTS: THE QUESTIONNAIRES AND INTERVIEWS AND THE IDENTIFICATION OF COMMON CONCEPTUAL DIFFICULTIES

6.1 Introduction

This chapter unites the results of the questionnaires and the interviews to the aim of this research which is the identification of the conceptual difficulties among college of education students and the lecturers in thermodynamics.

The results are discussed in terms of the principal student difficulties with the main concepts investigated namely; temperature, heat and energy, chemical reactions, entropy and spontaneity.

When student's views were compared from the pre-questionnaire to the post-questionnaire, it was found that though in most cases, students chose the correct option more frequently in the post-questionnaire, the reasons were mostly not correct. Analysis of the reasons given in the pre-questionnaire and post-questionnaire revealed that the initial alternative conceptions of students were mostly not existent in the post-questionnaire. However, there were some common alternative reasons which were persistent in the post-questionnaire. Most of the reasons given indicated that students have particular difficulties in understanding the concepts of entropy and spontaneity.

University, College of Science students generally showed a much better understanding of thermodynamics than college of education students after instruction.

6.2 Temperature, heat and energy

Items A1, A2, A3, A4 and A5 in the questionnaire addressed students and lecturers views about temperature and energy.

Difficulties in distinguishing between temperature, heat and energy across a broad range of situations including phase change.

Items A1, A3 and A5 required students and lecturers to explain what temperature measures in relation to the kinetic energy of the particles of a substance. This item required students to think at a microscopic level to be able to understand temperature as a measure of average kinetic energy. The majority of the lecturers performed well on these items, but the CEDS did not. Many students described temperature as a measure of the amount of heat an object contains. Some students related temperature to speed of particles. This belief led to a common conceptual difficulty that all particles (of the same substance) have the same speed and kinetic energy at a specific temperature.

Some students believed that both temperature and heat are energies. They used the two terms interchangeably as if meaning the same thing. For instance some students mentioned that temperature can be transferred from one object to another. There were some students who believed that since temperature increased due to the presence of an energy source, it implies that when the temperatures of two bodies are equal, they have the same heat.

Students conceptions of temperature equalisation in the interviews and questionnaires were satisfactory at a macroscopic level. The majority of the students mentioned that the temperature of bodies in thermal interaction will ultimately be the same. The explanations of this observation however were far from those of scientists. Their explanations revealed some confusion and uncertainty as to what is equalised; temperature, heat or energy? Some of this confusion could be emanating from the idea that two bodies have the same heat energy if they are at the same temperature.

In many instances, students used the word 'energy' to mean 'heat' and vice versa, as was found by Kesidou and Duit (1993) and Erickson (1979).

Items A2, A3 and A4 tested mainly ideas on phase change. Many lecturers performed well in these items. Some students believed that 'heat' and or 'temperature' caused expansion,

dissociation and breaking of bonds of particles allowing for free movement and random collisions of particles. This explanation was prominent in situations where a solid changed into a liquid. A conceptual difficulty often associated with this idea is that intermolecular bonds are confused with intramolecular bonds. For instance, some of the students said that during melting of methane, the bond between hydrogen and carbon breaks, freeing the carbon and hydrogen atoms. This lead to confusion in differentiating between physical change and chemical change.

Most students experienced difficulties in explaining the relationship between energy changes and phase change. Some viewed freezing as an endothermic change and melting as an exothermic change. Freezing appeared to be associated with the 'cold' sensation that accompanies endothermic changes. This may indicate that students were operating more on the macroscopic level than the microscopic. Failure to operate at both levels is bound to cause difficulties in understanding the energy changes associated with physical change.

From the above discussion it is easily understandable why conceptual difficulties exist in this area: the concepts of temperature and energy underpin any discussion of thermodynamics.

The majority of the lecturers and College of Science students showed a much better understanding of temperature and energy changes. Only three out of twelve lecturers shared the misconception that all the molecules of a substance have the same kinetic energy at a specific temperature. Surprisingly this misconception was identified only in the post-questionnaire.

6.3 Chemical reactions

No questions in the questionnaires were related to this concept.
The results of the interviews revealed some difficulties among students with chemical reactions. Students used both observational criteria and microscopic criteria to determine the requirements for a reaction to occur and the phenomena that indicate that a reaction has occurred, as summarised below:

Observational criteria

* temperature change
* nature of reactants
* heat given off to the surroundings

Microscopic criteria

* force of attraction between elements
* reactants possess energy
* difference in electronegativity of atoms of the reactants
* transfer of electrons between reactants

The idea that chemical reactions are occurring when there is an observable increase or decrease in temperature suggests that students may fail to realise that certain reactions occur without a noticeable temperature change.

Ideas about the nature of reactants show that students regard the state of substances as a criterion for a reaction to occur. Some believe that reactions will only occur if the reactants are homogeneous. This may reflect their predominant experience with reactions in solution. This idea is associated with difficulties in reactions where reactants are in different states. Ideas of state and homogeneity of substances as revealed by the students related more to the understanding of rates of reactions rather than their thermodynamics.

Student understanding of chemical reactions was mainly based on perceivable descriptions. Though some students tried to use microscopic descriptions, they revealed lack of correct knowledge. The idea of energy change in chemical reactions does exist but only vaguely.

6.4 Entropy

Items C1 to C6 in the questionnaires tested views held by students and lecturers on entropy. Ideas were identified in relation to (i) the nature of entropy and the identifying of entropy changes in processes (ii) factors affecting change in entropy and (iii) role of entropy in chemical and physical change.

Lecturers and CSCS performed much better than CEDS in the multiple choice section, but the reasoning revealed some common misconceptions among all groups to a varying degree. (See analysis of entropy in items D in chapter 5).

6.4.1 Nature of entropy and difficulties associated with identifying processes involving an increase or decrease of entropy

In items C1, C3 and C4 students and lecturers had to use given information to predict or decide if a process would have an increase or decrease in entropy.

The principal difficulties identified in both the questionnaires were:

Changes of randomness, movement, frequency of collision and speed of particles were seen as causes of an increase or decrease in entropy. This misconception was identified among lectures and students. For example air conditioning was regarded as a process accompanied by an increase in entropy. Probably the familiar everyday observation of the moving air around the fan dominated their thinking.

The principal difficulties identified in the interviews were:

a. entropy was equated with disorder
b. entropy was seen as the source for the disorder in the system
c. change in entropy was related to the change of spatial arrangement, randomness, frequency of collisions and speed of particles.

To the students disorder meant something different from what thermodynamics means with disorder. It appears that students did not understand the relationship between entropy and disorder. Only three students (in the interviews) gave the correct explanation that entropy is a measure of the disorder of the system, but when the same students were asked later to explain why the entropy of a heated gas increased, they said that entropy was the cause for the disorder of the system. This is virtually the opposite of the truth, namely "disorder" is the "cause" of entropy. Perhaps these students rote learned the definition of entropy from the textbooks without any conceptual understanding of the nature of entropy.

In both the interviews and questionnaires, students related changes in entropy with changes in the movement and speed of particles. In many instances students were able to state that entropy varied with temperature but their explanations were confusing. For example an increase in temperature increases randomness because it increased the speed of particles. Thus entropy was associated with the speed of particles and/or their kinetic energy change. The majority of students seemed to consider that when the speed of particles increases, the disorder will be larger due to more collisions. Low collision frequency relates to little and slow movement and high collision frequency to more and fast movements. Johnstone et al (1977) and Ribeiro (1992) also reported that students used more of the collision theory than thermodynamic principles in their explanations.

Perhaps the misunderstanding of the relationship between entropy and disorder is perpetuated by the analogy of the order and disorder of the stack of bricks that is used in many textbooks. Students fail to differentiate the meaning of disorder as is used in thermodynamics and its everyday use.

6.4.2 Factors affecting change in entropy

1. Temperature

Temperature was not mentioned as a factor affecting entropy, unless students were directly asked about its effect. The ideas identified were mentioned when the students tried to solve and explain other problems related to entropy changes. When students were asked to describe what happens to the entropy of a gas when its temperature is increased, most students said that the entropy will increase. The reasons given for the effect of temperature on entropy were however vague. The major reasons given were based on the movement and frequency of collision of particles. Though it is true that kinetic energy increases with temperature, students were expected to use the idea that entropy increases due to the increased number of ways a system has to store energy.

The lecturers and College of Science students scored well in most questions, but a few lecturers shared with the college of education students the idea of using the movement and frequency of collision of particles in explaining increases in entropy when the temperature

is increased.

2. State and size of particles

The size of particles was the main factor mentioned more in the interviews than in the questionnaires. When students were asked to choose the substance which will have the greatest entropy, most students mentioned gases and the size of individual atoms and molecules. A number of wrong criteria were used to explain why gases had the greatest entropy compared to liquids and solids.

(i) The size of the particles was related mostly to the speed at which particles move and the frequency of collisions. Small molecules with fewer atoms such as those of carbon dioxide were said to have a higher entropy because they can move more rapidly, thus increasing the frequency of collisions as compared to large molecules such as those of propane.

(ii) Some students indicated that large molecules with more atoms will have a higher entropy, but the reasons given show that they associated the larger number of atoms per molecule with increased movement of particles.

Criterion (ii) is partially correct but the number of atoms has an effect on the dispersal of energy in the molecules rather than leading to "increased movement of particles". No student ever explained the increase in entropy in terms of the greater mass of atoms which results in a greater number of ways a quantity of energy can be distributed among them.

In both criteria the students seem to perceive the movement of particles to be important in taking decisions about the magnitude of the entropy. The movement they are referring to is not related to the movement of atoms in the molecular structure (that is rotational and vibrational movements within the molecular structure) but to the speed of the molecules within a container. These ideas were used by students to explain why the entropy of solids was lower than that of liquids and gases. These ideas seem to reflect again confusion between entropy and kinetic energy. The idea of collision of particles is important in understanding rates of reactions rather than thermodynamics.

6.4.3 Role of entropy in chemical change and thermal equilibrium

In both the questionnaires and interviews students showed very little or no understanding of the role of entropy in chemical and thermal processes. Though the students indicated that for these processes to take place, the overall entropy change had to be positive, their reasons differed from those of the scientific community. Their major reason was that the positive change in entropy was due to the nature of reactants and products being either gas, liquid or solid. The state of a substance was regarded as the major contributing factor to the change in the overall entropy.

None of the students interviewed could explain why thermal equilibrium is established in terms of the overall entropy of both the system and the surrounding. Nor could they explain the spontaneity of chemical and physical processes in terms of the energy and the number of microstates. These difficulties further indicate that the second law of thermodynamics was not understood. Ribeiro (1992) reported similar results with fourth year undergraduate university students.

6.5 Spontaneity

Items D1 to D8 (chapter 4) tested students understanding of spontaneity in chemical and physical change.

The views of the students are discussed as (i) criteria used in determining spontaneity (ii) what causes processes to be spontaneous, (iii) understanding of the second law of thermodynamics and (iv) how non-spontaneous reactions could be made spontaneous.

In both the interviews and questionnaires, most students were confused about the conditions necessary for reactions to be spontaneous.

6.5.1 Criteria used in determining if a process will occur spontaneously

Students characterised a spontaneous reaction as follows:

1. activation energy not required,
2. occurs without any external interference,
3. change in enthalpy should be negative,
4. fast reaction,
5. heat evolves from the system to the surroundings.

The everyday use of the word 'spontaneity' brought confusion to many of the students. The idea that spontaneous reactions occur rapidly probably arises because of the daily use of the word 'spontaneous' which means 'immediate action' or 'rapidly'. This idea was dominant in the pre-questionnaire as well as in the post-questionnaire. Similar results were reported by Ribeiro et al (1990) with 4th year undergraduate university students in Portugal. The implication of this idea is that slow reactions are not spontaneous, eg. the rusting of a nail was classified as non-spontaneous.

Students classified a process as spontaneous if it was seen to be occurring without any external interference. This idea appeared in many explanations in the questionnaires. Such students perceived the supply of activation energy as an external interference, and hence all the reactions which were activated were classified as non-spontaneous. Some of the endothermic reactions which are spontaneous require activation energy to initiate the reaction. Perhaps, student's idea originate from the fact that many endothermic reactions usually require continuous supply of energy. Such processes were regarded as non-spontaneous just because the process had been activated.

The sign of change in enthalpy (ΔH) was also used as a determinant for spontaneity. A process with a positive change in enthalpy was classified as non-spontaneous. There were many supporting statements to the idea that only exothermic reactions are spontaneous, eg. "... a reaction is spontaneous when the change in enthalpy is negative". According to the students who hold this idea, reactions which are endothermic cannot be spontaneous. The conceptions identified here are again consistent with the belief that spontaneous reactions

do not need external interference. This idea was also reported by Ribeiro et al (1990) and Johnstone (1977).

Another criterion used by the students was an observation of the temperature change on the outside of the container. However, no sensible explanations were given as to why they thought an increase or decrease in temperature indicated that a reaction was spontaneous.

6.5.2 What makes processes spontaneous?

More than half the students interviewed did not explain spontaneous processes in terms of the change in free energy, unless they were asked to use this concept in their explanations. Though some of the students did refer to an energy change they were confused as to the type of energy involved. Some thought it was enthalpy, and hence they classified exothermic reactions, where energy is released to the surroundings, as the only spontaneous reactions.

Another criterion used was the movement and collision of molecules. Some examples of the students statements from interviews and questionnaires are:

"spontaneous reactions occur because of an increase in the numbe of mole .... which results in an increase in volume and a greater number of collisions and randomness....."
" an increase in kinetic energy of the reactants molecules results in an increase in the number of collisions of molecules, making a process spontaneous..."

Students who used free energy change in their explanations, (only when they were asked to do so in the interviews) showed a superficial understanding of the concept. Six students (in the interviews) defined free energy as the energy taken out or lost by the system to the surroundings during a reaction. This definition further strengthens the idea that exothermic reactions are regarded as spontaneous.

In many instances ΔH and ΔG were regarded as the same thing. This was evident in many questionnaire responses where a negative change in enthalpy was taken as implying a

negative change in free energy, implying that the reaction was spontaneous. This idea was predominant in both questionnaires and interviews.

6.5.3 Students understanding of the second law of thermodynamics

The ideas relating to this were mainly collected from the interviews.

Students understanding of the relationship between the different terms in the equation $\Delta G = \Delta H - T\Delta S$ in determining the direction of spontaneity was also tested. Eight students were able to give the correct equation, but when asked to give a qualitative explanation, the majority showed a vague understanding. Only two students gave a correct interpretation of the equation. To some students for ΔG to be negative, it depends on the value of ΔS, which should be always greater than ΔH. To other students, the reverse of the latter statement made more sense to them. In both cases the effect of varying temperature on the feasibility of reactions was not mentioned.

It seems students were familiar with calculating free energy change using the formula without understanding the conceptual relationship between the different terms in the equation. The students in general were able to memorise formulae and equations without understanding the concepts and principles involved. This was also evident in the questionnaires. Students might respond correctly to the multiple choice options but their explanations were far from those of scientists. Similar results, where students could use the mathematical equation in problem-solving but failed to understand the conceptual relationship between the different terms in the equation, were reported by Granville (1985) and Ribeiro et al (1990).

6.5.4 Can non - spontaneous reactions be made to occur?

In both the questionnaires and interviews, students stated that non-spontaneous reactions could be made to occur. The predominant ideas about the conditions necessary to make non-spontaneous reaction occur were:

* adding activation energy in the form of heat to initiate a reaction

* adding a catalyst

The two ideas above show confusion between the factors affecting the rate (kinetics) of a reaction and those affecting spontaneity (thermodynamics). Bapoo (1995) identified similar confusion with standard 8 and 9 students. These ideas were common in both the pre-questionnaire and the post-questionnaire . The belief that energy, mainly in the form of heat, is added to initiate a non-spontaneous reaction is erroneous. Some spontaneous reactions are very slow because of a high activation energy; energy is required to initiate the reaction. Once a reaction has been initiated, it may continue on its own without further addition of energy. Such a reaction will still be spontaneous. A catalyst cannot change a thermodynamically unfavourable reaction to one that is thermodynamically favourable.

In conclusion, the questionnaires showed that the lecturers had similar wrong ideas to the college of education students. These were:
(a) exothermic reactions are spontaneous,
(b) spontaneous reactions do not require activation energy to initiate the reaction,
(c) a non-spontaneous reaction can be made to occur by giving it activation energy,
(d) a non-spontaneous reaction can be made to occur by adding a catalyst.

The existence of these misconceptions among lecturers suggests that they could be sources of student misconceptions about spontaneity.
The College of Science students shared very few of the misconceptions held by the college of education lecturers and students.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

Table 7.1 The overall percentages of participants choosing correct multiple choice responses

	Pre-questionnaire %	Post-questionnaire %
Lecturers (LECT)	62.5	75.0
College of education students (CEDS)	19.6	28.9
College of Science students (CSCS)	-	77.8

The results in the above table for both questionnaires show knowledge gains on the part of CEDS and LECT. However, though there was an increase with CEDS, the low average mark in the post-questionnaire indicates that in general they did not understand the underlying concepts of thermodynamics even after instruction. It may be assumed that the majority of the students involved in this study are presently teaching science at senior level in the high schools. The conceptual misunderstandings they have may be transferred to the pupils they are teaching. Due to the small sample of CEDS, LECT and CSCS, one cannot deduce too much from the overall comparisons. However, the qualitative conclusions seem unavoidable.

7.2 Deductions about student-teacher knowledge

The results of this study revealed that the college of education students' ideas described in chapter 4, 5 and 6 before and after instruction, are partly a consequence of their previous ideas (eg. from school) and partly of the ideas acquired via instruction at the college. The pre-questionnaire revealed that student knowledge of basic concepts from school and even after the two years of Secondary Teacher's Diploma curriculum prior to third year at the college was poor. Unfortunately, it is common to assume in the college that basic concepts such as those dealing with the kinetic molecular theory, temperature, heat and energy changes have been learned in the secondary schools.

The results of the post-questionnaire and interviews indicated that many of the students even after instruction, had a poor understanding of these basic concepts, especially at the microscopic level. Students were able to say for example that when two bodies at different temperatures come into contact with one another after some time their temperatures will be equal. However, what is equalised at the molecular level is usually not known. These results show that student-teachers may even leave the college and join the teaching profession without a clear understanding of some basic concepts.

As regard the basic concepts like heat, temperature and energy, the views of the student-teachers were similar to school children's views reported by researchers such as Driver et al (1985), Thomaz et al (1995) and others cited in the literature review (chapter 2).

The teaching programme at colleges of education should take students conceptual difficulties into consideration. The idea of thermal equilibrium should be illustrated using simple experiments and everyday phenomena. One may argue that the activities might be too simple for the tertiary students, but the reality is that these students have problems that need to be solved from the roots. Many of the students, though they have gone through science instruction from higher primary and secondary school level, still lack experience in associating everyday phenomena with what is learned in the science classroom.

This research revealed a poor conceptual understanding of entropy and spontaneity by student-teachers even after teaching. Their views of these more advanced concepts were similar to those of tertiary students reported by researchers such as Ribeiro et al (1990), Ribeiro (1992) and others. It may be suspected from the results of the pre- and post-questionnaire that alternative background knowledge of the student-teachers on the basic concepts mentioned above had a negative effect on STD 3 thermodynamics teaching.

There is a need to introduce entropy in a more meaningful way so that the students can appreciate that S is a real quantity and recognise its importance in understanding the spontaneity of physical and chemical changes. A good understanding of spontaneity could be achieved by first looking at activities or phenomena familiar to the students and then by introducing the abstract nature of the concept.

7.3 Deduction about lecturer's knowledge

Certain lecturers lack correct knowledge of thermodynamics concepts. Both questionnaires showed that some lecturers have misconceptions themselves. Some of the misconceptions they have are similar to those of the students. This in part at least explains why the STD 3 students learning is not successful.

College lecturers need to be aware of wrong ideas that may be developed by their own teaching as well as wrong ideas about basic concepts such as heat, temperature, thermal equilibrium and energy changes taught at school.

7.4 Deductions about the College of Science students

The CSCS showed a much better understanding of the more advanced thermodynamics concepts. The better post-questionnaire results may be attributed to (i) teaching methodologies, (ii) staff quality and (iii) student quality.

(i) Teaching methodologies

The College of Science is implementing good methodologies that are evidenced through research globally to enhance meaningful learning. Their innovative teaching methodologies take students prior knowledge into consideration. Survey of knowledge tests are administered before and after teaching every topic in the science syllabus. The lectures are supplemented by small group tutorials and practical work.

(ii) Staff Quality

The staff is better qualified to teach chemistry. Some colleges of education do not have science lecturers who are qualified to teach chemistry major at colleges. This happens because at the present moment the country still has a major shortage of highly qualified science teachers.

(iii) Student Quality

The College of Science admits students who obtained a satisfactory matric pass but need to improve on their chemistry and physics to be able to enter main stream science at the University.

7.5 Teaching methodologies

This research on students at five colleges of education is in parallel with one completed by Mosimege (1996) on students at another college of education. He reported conceptual difficulties regarding some concepts on acids and bases. The results of these two researches indicate a strong probability of the existence of difficulties with other topics and at other colleges of education. This clearly justifies a broad investigation into the needs of student teachers and lecturers as well as the science curricula at colleges of education.

The enrolment of students at universities and technikons is determined by a number of factors, e.g. first class pass in matric mathematics and science. Many of the weak students go to colleges of education. Therefore, colleges of education cannot avoid admission of low quality matric students. One of the solutions to the problem is to accept this reality and improve on the teaching methodologies accordingly.

The fact that some alternative ideas were prevalent even after instruction suggests that the teaching methodologies used in the colleges are not appropriate to teaching thermodynamics. Indeed informal observations about science teaching methodologies at colleges of education indicate they often do not foster meaningful understanding of science.

The difficulties experienced by students that have been revealed in this research indicate that their conceptual understanding of heat, energy, temperature, entropy and spontaneity need to be addressed. If science educators believe that conceptual understanding is important, then they should teach students about the processes of achieving this. Assessment should also focus on conceptual knowledge, then students will see the need and the importance of developing the skills and abilities required for conceptual understanding. Pickering (1990) has shown that when conceptual development processes are taught and developed, students conceptual understanding improves dramatically.

The teaching programmes at colleges of education should take into account students prior conceptual knowledge. Lecturers should not assume that students have learnt fundamental concepts and theories such as kinetic molecular theory at high school. This research has

revealed that many of the students still lack an understanding for example, of what is happening at molecular level during a phase change when the temperature remains constant.

To those involved in teacher education curriculum development and to the education authorities in general, I will recommend that the preservice and inservice training programmes for science teachers should include intensive instruction in science content using teaching strategies designed for meaningful learning. The inclusion of studies on misconceptions and theories of constructivism in the college science curriculum will help make students aware of their own misconceptions in different topics. The present curriculum does not emphasise the teaching of the problem of misconceptions in science and the identification of prior knowledge (preconceptions) about science topics.

Mosimege (1996) suggested that if student-teachers are made aware of the misconceptions they have about science topics, they will in turn see the importance of identifying the same in their learners when they enter the teaching profession. Again, training in identification of misconceptions will help make them authorities in the subjects they teach. This knowledge may also motivate student-teachers and teachers to become critical of what they read in the textbooks and also in their year to year lesson preparations.

The teaching methodologies now being used by EMSCEP(Eskom mathematics and science colleges of education project)(1996) for the "second-chance" matric course are highly recommended for use at colleges of education. The teaching approaches designed in the resource packages for students allow individual students to learn science with meaningful understanding at different paces. This is in fact in line with the new South African curriculum initiative on outcome-based education (Department of Education, 1997).

Finally, I recommend development of a teacher resource package that will, amongst other things, address the conceptual difficulties identified here.

7.6 Some general recommendations regarding improvement in science-teacher education in South Africa

(1) There is a need to introduce bridging programmes at colleges of education (like the College of Science at Wits University), in order to ameliorate the problem of post-matric students who are ill-prepared to cope with the college of education science curriculum.

(2) Most of the "good quality" matriculants in South Africa go to universities and technikons. Only a few register at colleges of education. Since the country is in great need of science, mathematics and technology teachers, it is recommended that incentives for students who want to be science teachers be provided. This, although contentious, will probably invite more quality matric science students into colleges of education.

(3) The research has revealed that some college lecturers are not well prepared to teach thermodynamics. This problem could be solved by appropriately designed FDE (Further Diploma in Education) programmes and inservice training courses to teach thermodynamics.

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PRE-QUESTIONNAIRE FOR CHEMICAL THERMODYNAMICS

The purpose of this questionnaire is to ascertain the views that you have concerning key concepts related to Chemical Thermodynamics. You will not be graded on these results. It is very important that the researcher find out what your ideas and problems are.

There is no time limit. Consider your options carefully. If you feel one or more options is only half correct avoid choosing such an answer. Look for the responses that summarises your understanding of the concept.

In order to make your responses meaningful, you are requested not to obtain answers from another student or lecturer.

INSTRUCTIONS

* In the space marked STUDENT NUMBER, write your date of birth in the sequence of day, month and year, eg. 28 January 1969 would be written 280169.

* In the space marked SURNAME, write any pseudonym, which you are likely to remember.

* The date will be the one you respond to the questionnaire.

STUDENT NUMBER: ☐

SURNAME AND INITIALS: ☐

DATE:

STUDENT: ☐ [Tick the relevant box]

LECTURER: ☐

SECTION A
MULTIPLE CHOICE QUESTIONS
** Encircle the correct symbol representing your answer. Write your reasons on the answer sheet provided.*

1. At the given temperature
   - A. all substances have the same total energy
   - B. all molecules have the same velocity
   - C. the average kinetic energy of any collection of atoms is the same
   - E. none of the above

2. An example of an endothermic change is the
   - A. melting of a compound with a network structure
   - B. formation of a chemical bond
   - C. freezing of a liquid
   - D. expansion of an ideal gas into vacuum
   - E. mixing of concentrated sulphuric acid with water

3. When a solid substance at 0 K is allowed to increase in temperature (but not so far as to melt), the component atoms
   - A. increase their nuclear energy
   - B. decrease their rotational energy
   - C. increase their vibrational energy
   - D. undergo dissociation
   - E. do not change their kinetic energy

4. When a solid methane, CH_4 at -184°C (its melting point) is converted to liquid methane at the same temperature
   A. the methane molecules gain kinetic energy
   B. C-H bonds are broken
   C. the intermolecular forces are weakened
   D. the methane molecules expand
   E. the molecules decrease in potential energy

5. When a piece of hot metal is placed in a beaker of cold water, exchange of energy occurs until the metal and water have the same
   A. total kinetic energy
   B. temperature
   C. internal energy
   D. heat capacity
   E. quantity of thermal energy

6. In a chemical reaction equilibrium
   A. the balanced chemical equation is no longer true since the reaction does not go to completion
   B. the concentration of the reactants and products are equal
   C. the internal energies of the reactants and products are equal
   D. the mass of substances on the left hand side of the equation equals the mass of the substances on the right hand side
   E. the reactants continue to form products, but the products reform reactants at the same rate

7. Which of the following statements about a system at equilibrium is incorrect?
   A. The expression of the equilibrium constant may be deduced from the balanced chemical equation.
   B. The free energy of the system is at minimum.
   C. The position of equilibrium is temperature dependant.

D. The value of the equilibrium constant under standard conditions can be calculated from standard free energy data.

E. The position of equilibrium may be predicted from a knowledge of the enthalpies of reactants and products.

8. Choose which of the following reactions is accompanied by a large increase of disorder of the system?

A. $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

B. $FeSO_4.7H_2O(s) \rightarrow FeSO_4(s) + 7H_2O(g)$

C. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

D. $(NH_4)_2SO_4(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + 2NH_4Cl(aq)$

E. $CH_4(g) + 2Cl(g) \rightarrow CH_2Cl_2(g) + 2HCl_2(g)$

9. A chemical reaction will occur when

A. the system liberates heat to the surroundings

C. elements form compounds

D. heat is applied to a system to get it started

E. reactants mix homogenously

10. Which one of the following reactions will occur in the directions written?

(i) $CuSO_4.5H_2O \rightarrow CuSO_4.H_2O + 4H_2O$ $\Delta H > 0$

(ii) $N_2 + 3H_2 \rightarrow 2NH_3$ $\Delta H > 0$

(iii) $2NH_3 \rightarrow N_2 + 3H_2$ $\Delta H > 0$

(iv) $3O_2 \rightarrow 2O_3$ $\Delta H > 0$

(v) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ $\Delta H > 0$

A. (i), (iii) and (v)

B. (ii) and (v) only

C. (iii) and (v) only

D. (iii) only

E. All of the above reactions

11. Which one of the following statements about thermodynamic spontaneity is correct?
    A. spontaneous reactions all occur at a rapid rate
    B. for a spontaneous reaction, $\Delta G < 0$
    C. for a spontaneous reaction, $\Delta G = T\Delta S_{tot}$
    D. spontaneous reactions go to completion
    E. for a spontaneous reaction, $K < 1$

12. Which one of the following statements about thermodynamic spontaneity is an <u>incorrect</u> statement of the second law of thermodynamics?
    A. Every system which is left to itself will, on the average change to a condition of maximum probability
    B. In a spontaneous process, the total disorder of the system is increased
    C. Heat cannot spontaneously pass from a colder body to a hotter body
    D. The state of maximum probability is the most stable state for a system
    E. all the heat obtainable from a system can be converted into work

13. Which one of the following is correct for the phase change?
    H_2O (s) ⇌ H_2O (l) at 0°C

	ΔH	ΔS(degree of disorder)	ΔG(measure of spontaneity of reaction)
A.	-	-	+
B.	-	+	0
C.	+	+	-
D.	+	+	0
E.	-	-	0

14. Which one of the following statements about the effect of increasing temperature on the thermodynamics quantities is <u>incorrect</u>?
    A. the enthalpy of a substance increases
    B. the free energy change of a reaction either increases or decreases
    C. the degree of disorder of a reaction increases
    D. the disorder of a substance increases

E the enthalpy change of a reaction remains roughly unchanged

The pairs of diagrams on the last page are microscopic representations of initial and final situations for a number of processes. Use these diagrams in answering questions 15 and 16.

15. The pair(s) of diagrams in which the process represented must involve a decrease in the entropy of the system is/are
    A. 4 only
    B. 2 and 5 only
    C. 1, 3, 4 and 5 only
    D. none
    E. all of them

16. The pair(s) of diagrams in which the process represented must involve a decrease in entropy of the surroundings is/are
    A. 4 only
    B. 2 and 5 only
    C. 1, 3, 4 and 5 only
    D. none
    E. all of them

CHEMICAL THERMODYNAMIC PRE-QUESTIONNAIRE

SECTION B

B. Decide whether the following statements are True or False
Mark the relevant box (T or F) with a cross. Thereafter, in the space provided, explain your answer.

1. Only exothermic reactions are spontaneous reactions.

T	F

2. Spontaneous reactions may be fast or slow.

T	F

3. Spontaneous reactions occur because weak bonds in the reactants break and form strong bonds in the products.

T	F

4. Spontaneous reactions occur because the positive and negative charges of the reactants attract each other

T	F

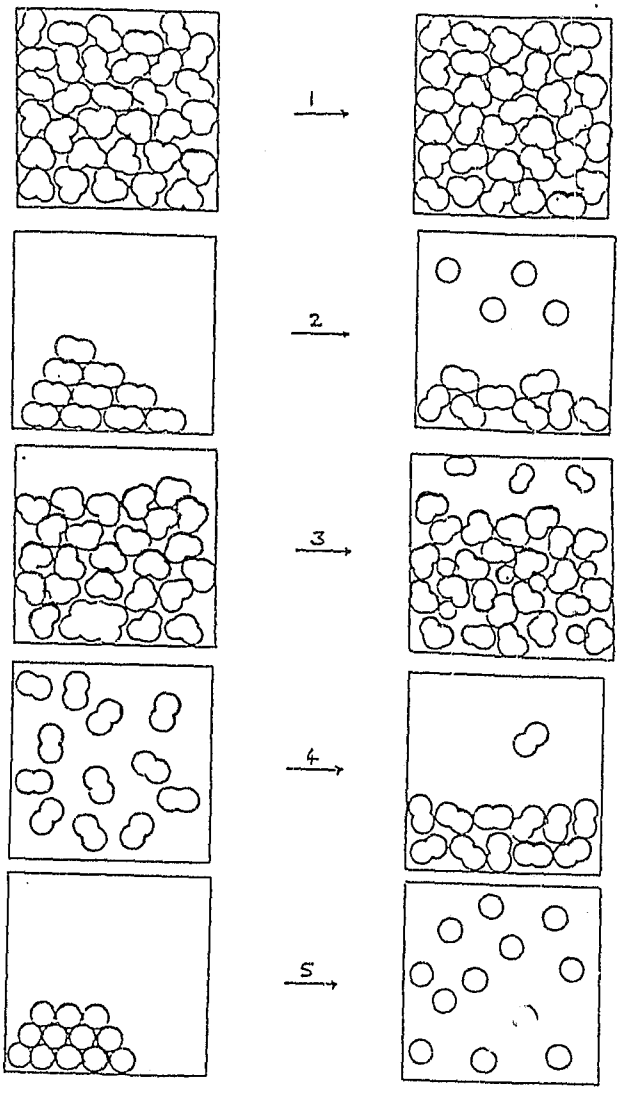
5. The rusting of iron-nail is spontaneous

T	F

6. Non-spontaneous reactions can never occur.

T	F

DIAGRAMS FOR QUESTION 15 AND 16



POST-QUESTIONNAIRE FOR CHEMICAL THERMODYNAMICS

The purpose of this questionnaire is to ascertain the views that you have concerning key concepts related to Chemical Thermodynamics. You will not be graded on these results. It is very important that the researcher find out what your ideas and problems are.

There is no time limit. Consider your options carefully. If you feel one or more options is only half correct avoid choosing such an answer. Look for the responses that summarises your understanding of the concept.

In order to make your responses meaningful, you are requested not to obtain answers from another student or lecturer.

INSTRUCTIONS

* In the space marked STUDENT NUMBER, write your date of birth in the sequence of day, month and year, eg. 28 January 1969 would be written 280169.

* In the space marked SURNAME, write the pseudonym, which you used in the previous questionnaire.

* The date will be the one you respond to the questionnaire.

STUDENT NUMBER: ☐

SURNAME AND INITIAL: ☐

DATE:

STUDENT: ☐ [Tick the relevant box]

LECTURER: ☐

MULTIPLE CHOICE QUESTIONS ON CHEMICAL THERMODYNAMICS

Please attempt all questions.

Encircle the correct symbol representing your answer. Write your reasons for each response below each question.

1. At the given temperature
   - A. all substances have the same total energy
   - B. all molecules have the same velocity
   - C. the average kinetic energy of any collection of atoms is the same
   - E. none of the above

---

2. When a solid substance at 0 K is allowed to increase in temperature (but not so far as to melt), the component atoms
   - A. increase their nuclear energy
   - B. decrease their rotational energy
   - C. increase their vibrational energy
   - D. undergo dissociation
   - E. do not change their kinetic energy

---

3. When a piece of hot metal is placed in a beaker of cold water, exchange of energy occurs until the metal and water have the same
   - A. total kinetic energy
   - B. temperature
   - C. internal energy

D. heat capacity
E. quantity of thermal energy

4. Which of the following statements about a system at equilibrium is incorrect?
   A. The expression of the equilibrium constant may be deduced from the balanced chemical equation.
   B. The free energy of the system is at minimum.
   C. The position of equilibrium is temperature dependant.
   D. The value of the equilibrium constant under standard conditions can be calculated from standard free energy data.
   E. The position of equilibrium may be predicted from a knowledge of the enthalpies of reactants and products.

5. In which of the following processes does a the total entropy of the system increase?
   A. Air conditioning a house
   B. Separating coins by denomination
   C. Making a bottle of lemonade or glass of Cool-Aid drink
   D. Putting together a jigsaw puzzle
   E. Packing a refrigerator

6. A chemical reaction will occur when
   A. the system liberates heat to the surroundings
   C. elements form compounds
   D. heat is applied to a system to get it started
   E. reactants mix homogenously

7. Suppose we have a mole of gaseous neon in a 20 l container at 300 K. We then heat it at a constant volume to 400 K. The entropy of the gas increases,
   A. because the average kinetic energy of the atoms increases
   B. because of the increase in temperature
   C. because heating increases the internal energy of the atoms

D. because of the increased possible number of ways a system has to store energy
E. Because the atoms are moving more randomly than before

8. Which of the following equations represents a reaction that is accompanied by the largest increase of the disorder of the system?

A. $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
B. $FeSO_4.7H_2O(s) \rightarrow FeSO_4(s) + 7H_2O(g)$
C. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
D. $(NH_4)_2SO_4(aq) + BaCl_2(aq) \rightarrow BaSO_4(s) + 2NH_4Cl(aq)$
E. $CH_4(g) + 2Cl(g) \rightarrow CH_2Cl_2(g) + 2HCl_2(g)$

9. Spontaneous reactions occur because
A. reactants do not require activation energy to initiate the reaction
B. of the difference in the electronegativities of the reactants
C. the energy of the reactants is lower than of the products
D. the energy of the reactants is higher than that of the products
E. The total entropy increases

10. Which one of the following reactions will occur in the directions written?

(i) $CuSO_4.5H_2O \rightarrow CuSO_4.H_2O + 4H_2O$ $\Delta H > 0$
(ii) $N_2 + 3H_2 \rightarrow 2NH_3$ $\Delta H > 0$
(iii) $2NH_3 \rightarrow N_2(g) + 3H_2$ $\Delta H > 0$
(iv) $3O_2 \rightarrow 2O_3$ $\Delta H > 0$
(v) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ $\Delta H > 0$

A. (i), (iii) and (v)
B. (ii) and (v) only
C. (iii) and (v) only
D. (iii) only
E. All of the above reactions

11. Which one of the following statements about thermodynamic spontaneity is correct?
    A. spontaneous reactions all occur at a rapid rate
    B. for a spontaneous reaction, $\Delta G < 0$
    C. for a spontaneous reaction, $\Delta G = T\Delta S_{tot}$
    D. spontaneous reactions go to completion
    E. for a spontaneous reaction, $K < 1$

12. Which one of the following is correct for the phase change?
    H_2O (s) ⇌ H_2O (l) at 0°C

	ΔH	ΔS(degree of disorder)	ΔG(measure of spontaneity of reaction)
A.	-	-	+
B.	-	+	0
C.	+	+	-
D.	+	+	0
E.	-	-	0

13. A non-spontaneous reaction can be made to occur by
    A. Adding a catalyst
    B. Giving it an activation energy
    C. Supply it with reactive molecules
    D. Addition of heat
    E. Performing some work on the reaction continuously

14. A certain chemical reaction has a ΔH of +122kJ/mol and ΔS of 231JK^{-1} mol^{-1}. At what temperature does this reaction proceed spontaneously?
    A. At all temperatures
    B. At 0 kelvin
    C. At high temperature only
    D. At low temperature only

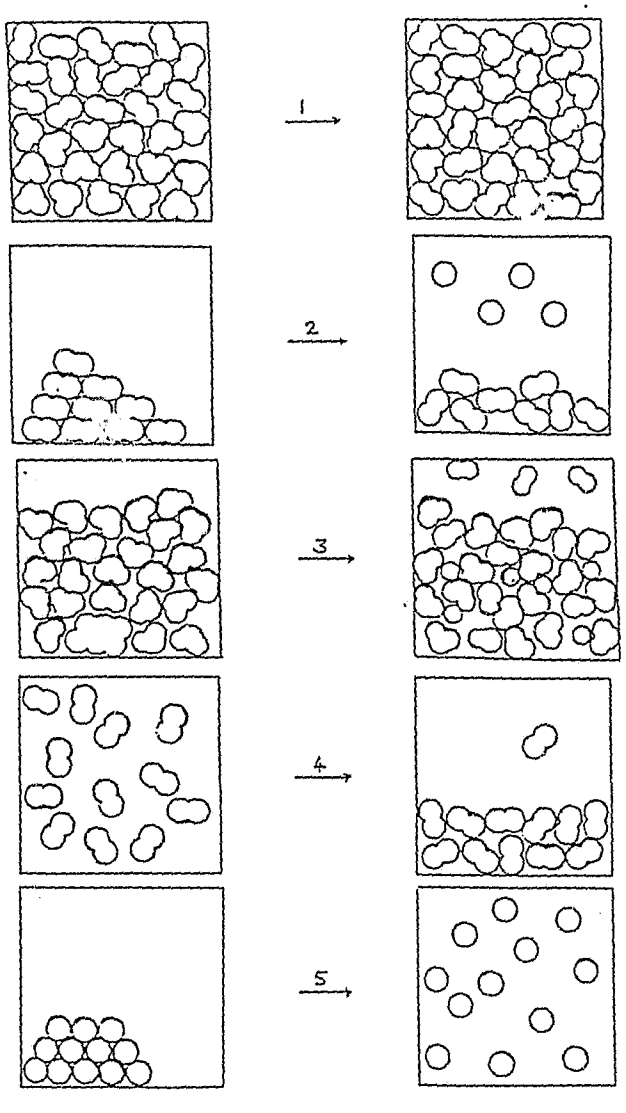
E. This reaction will not proceed spontaneously at any temperature

The pairs of diagrams on the last page are microscopic representations of initial and final situations for a number of processes. Use these diagrams in answering questions 15 and 16.

15. The pair(s) of diagrams in which the process represented must involve a decrease in the entropy of the system is/are
A. 4 only
B. 2 and 5 only
C. 1, 3, 4 and 5 only
D. none
E. all of them

16. The pair(s) of diagrams in which the process represented must involve a decrease in entropy of the surroundings is/are
A. 4 only
B. 2 and 5 only
C. 1, 3, 4 and 5 only
D. none
E. all of them

DIAGRAMS TO QUESTIONS 15 AND 16



APPENDIX C

INTERVIEW TRANSCRIPTS

ELIJAH MANGO COLLEGE OF EDUCATION

I = Interviewer

Interview No. 1

1.	I:	How does the free energy works in a body?
2.	G:	It determines as to wether the body can undergo a spontaneous reaction or not. I think if free energy is very low or lost, the body would need some other energy.
3.	I:	What other energy are you speaking about?
4.	G:	I think it is heat energy.
5.	I:	Is it only the heat energy?
6.	G:	I think also thermal energy.
7.	I:	What is the difference between thermal energy and heat energy?
8.	G:	I think there is no difference, because both have something to do with the temperature. Thermal energy I should think is the energy of the temperature.
9.	I:	According to you, heat energy can be added to make reactions spontaneous. So when will you add this energy. At the beginning or start of a reaction or just continuously?
10.	G:	It depends on the type of reactants, because some may be after getting that little energy, called activation energy then they can occur spontaneously, but at the beginning they would not occur. They needed some little activation energy to make it spontaneous. There are some, which need application of heat continuously to occur.
11.	I:	How will you determine wether a reaction would occur or not without doing experiments. You said something about the tables. Which tables will you use
12.	G:	We have a table of the list of enthalpies and entropies and Gibb's function.
13.	I:	How will you use the table?
14.	G:	I think one will look at ΔH of reactant A and ΔH of B. If their sum is positive, I think the reaction is non-spontaneous.
15.	I:	With the exception of enthalpies and free energy change tables , is there any other quantity that you can use to determine the spontaneity of a reaction?
16.	G:	There is entropy.
17.	I:	What is entropy?
18.	G:	Is the measure of the degree of disorder of a substance.
19.	I:	How will it help us to determine if ever a reaction will occur or not.
20.	G:	When we combine the two entropies of the reactants, if they give a negative sign it would mean that there is a decrease in the disorder and that reaction cannot occur.
21.	I:	Disorder of what?
22.	G:	Disorder of particles.
23.	I:	What do you mean by "disorder"
24.	G:	If we take for instance, an ice cube, this is going to melt spontaneously in the beaker to form liquid. Ice is more in the orderly manner than liquid. Because ice melt spontaneously , then the change in entropy is positive because it is from lower disorder to higher disorder. If delta S is positive, the reaction will occur spontaneously.
25.	I:	What does delta S positive mean?

26.	G:	How?
27.	I:	Sometimes when you read a chemical equation at the end it will be written; ΔS is positive. What does ΔS positive signify?
28.	G:	It means that work has been done to the system.
29.	I:	What type of work?
30.	G:	I mean ... like in the case of melting. Work has been done to change it from one phase to another.
31.	I:	Carbon Dioxide and propane are both gases. Which gas will have the greatest entropy at room temperature?
32.	G:	If they are put in equal containers?
33.	I:	Yes, and the volume is also the same. Both containers are closed. Which gas will have the greatest entropy?
34.	G:	Carbon Dioxide
35.	I:	Why carbon dioxide?
36.	G:	A carbon dioxide molecule has got three atoms and propane has got eleven atoms. So if we put carbon dioxide in a test tube it will have a larger space to move than particles of propane. Particles of propane will be compressed as compared to free particles of carbon dioxide.
37.	I:	Can you summarise your response?
38	G:	Carbon dioxide particles will have a bigger space to move, so the randomness of the particles will be greater than that of propane.
39.	I:	What do you understand by the word randomness?
40.	G:	The movement of the particles in carbon dioxide will be very much disorganised than in propane, because propane particles are many, so they have little space to move in.
41.	I:	Suppose we have gaseous hydrogen in a ten litre container, at 25 °C. The container is then heated to 50 °C. What will happen to the entropy of the gas?
42.	G:	The entropy will increase.
43.	I:	Why?
44.	G:	Because the increase in temperature increases the kinetic energy of the particles. There will be more disorder when the temperature is increased.
45.	I:	Will this increase in temperature have an effect on individual molecules?
46.	G:	It will have an effect on the average kinetic energy of all the molecules.
47.	I:	How will it affect the average kinetic energy?
48.	G:	The average kinetic energy will increase so that particles will have a higher speed. The higher speed will increase the entropy.
49.	I:	Can a change in temperature affect the free energy change?
50.	G:	Yes, temperature has got some effect.
51.	I:	How?
52.	G:	When you increase the temperature of a substance, the heat content is also increased. So I think the free energy of a substance is also affected.
53.	I:	How will it be affected?
54.	G:	I do not know.
55.	I:	Will we have a reaction when we mix iron fillings and sulphur powder at room temperature?
56.	G:	I do not think it will occur.
57.	I:	Why?
58.	G:	Because this is a non-spontaneous reaction.
59.	I:	How will you make it to occur?
60.	G:	May be if we can heat this, it will start reacting.
61.	I:	How long will you heat this?
62.	G:	I do not know.
	END : GIVEN	

Interview 2
Student: Reuben = ..

63.	I:	What happened in the first demonstration?
64.	R:	The ammonium chloride dissolved in water and the reaction is endothermic since it absorbed heat from the surroundings. This test tube is cold.
65.	I:	What about the second demonstration?
66.	R:	A reaction occurred because the test tube is warm when the water mixes with nitric acid.
67.	I:	Will there be a reaction when we mix iron fillings with sulphur powder?
68.	R:	No
69.	I:	How will you make it react?
70.	R:	I think if we can increase energy here.
71.	I:	How?
72.	R:	By heating the contents of the crucible, I think we can have a reaction between the two.
73.	I:	How long will you heat it?
74.	R:	Until the sulphur is dissolved.
75.	I:	What causes the sulphur to dissolve?
76.	R:	The heat will dissolve sulphur.
77.	I:	What are spontaneous reactions?
78.	R:	Reactions which occur on their own, without adding energy. For example : In the previous demonstrations we mixed water and ammonium chloride. This reaction is spontaneous.
79.	I:	What about the mixture of iron fillings and sulphur powder?
80.	R:	It is not spontaneous.
81.	I:	How can you make it spontaneous?
82.	R:	By heating the mixture.
83.	I:	Are there other ways and means that you can use to make the reaction spontaneous?
84.	R:	We can add a catalyst. A catalyst can make a non-spontaneous reaction to be spontaneous. There are also other ways but a catalyst is what I can remember now.
85.	I:	What is a chemical reaction from your view point? We talk a lot about chemical reactions in chemistry.
86.	R:	Chemical reaction is when chemicals,for instance is when elements mix to form compounds,or when compounds and compounds are put together that is a chemical reaction.
87.	I:	Why do you think these reactions should happen?
88.	R:	I am not sure.
89.	I:	For example, when you mix kool-aid powder with water, it just mix easily. Why does it not turn back into water and kool-aid crystals?
90.	R:	I think they are of the same nature. For example, they are polar. If they are different, we may not get a chemical reaction, e.g. Paraffin and water cannot mix because they are not of the same nature. One is polar and the other is non-polar. When you add water in potassium permanganate, it dissolves, indicating a reaction because they are all polar substances.
91.	I:	Why do certain events occur in a particular direction. It may be chemical change or physical change.
92.	R:	(Silent for sometime)
93.	I:	Lets assume that we have body A and body B. Body A is at a temperature of 20 °C and body B at 10 °C. What will happen to the two bodies if they are made to come into contact with one another? The bodies are made of the same material e.g. brass or steel
94.	R:	If for instance when they come together, the temperature must be balanced. I think body A since it is 20 °C and body B is 10 °C, they will have to share the temperature. That is body B will get some few heat or energy from body A so that

they will reach equilibrium and hence have equal temperatures.

95. I: How does temperature balance occur?

96. R: (silent for some time)

97. I: How does heat move from A to B?

98. R: I think the heat from surrounding of A will heat the particles next to A and those particles will heat particles next to B, in that form the heat will then be transferred to B.

99. I: Do you expect any transfer of heat from B to A?

100. R: No, I do not think B will transfer heat to A since they will all have equal temperatures. No one is less than the other one. So they will just remain with that amount they have since they are equal.

101. I: I want you to explain using this example why do we have certain events going in a particular direction not turning back. Just like when you have dissolved ammonium chloride in water. Can we rapidly get ammonium chloride again in this powder form?

102. R: I think we have to do something in order to get it means spontaneous reaction occurs at 25 °C, so may be the reverse may occur in some other temperatures. May be if we can decrease the temperature, may be that ammonia can decrease to a solid, or by evaporating all the water. May be by decreasing or increasing the temperature we can have the reaction turning spontaneous.

103. I: When is the reaction spontaneous?

104. R: The reaction can be spontaneous in that environment were it exists is fit for it but if it is not fit for that reaction to occur it is not spontaneous. The reaction need conditions for it to be spontaneous.

105. I: What are the conditions?

106. R: For the ammonium reaction to be spontaneous it need a temperature of 25°C, may be if we were to use 0°C, I think it was not going to happen. That condition there is not fit for it.

107. I: You would like to do an experiment but you are not sure that it will happen. How will you determine that the substances you have will react before you start with the experiment.

108. R: I can use may be the polarity.

109. I: How will you determine the polarity?

110. R: I am not sure. May I can use the periodic table, because some hydrocarbons does not react with water.

111. I: Is it the only table you can use?

112. R: Even using the hmmm...at my disposal I can only remember this.

113. I: Carbon dioxide plus propane are both gases. Which of the two gases will have the greatest entropy?

114. R: Propane will have the greatest entropy.

115. I: Why?

116. R: Because propane has more carbons bonded to many hydrogens than carbon dioxide.

117. I: So, how does the number of atoms affect the entropy?

118. R: The movement of particles in the propane is more than in carbon dioxide.

119. I: Suppose we have hydrogen gas at 20 C. We then heat the container to 50 C. What will happen to the entropy of the system?

120. R: It will increase since the particles of the gas will gain energy and become more excited and there will be more disorder in the container and hence the entropy will increases.

121. I: What type of energy be gained?

122. R: I think is the internal energy.(though I am not sure).

123. I: Suppose you have a gas container connected with a pump to another closed empty container. We open the tap. What do you think is going to happen?

124. I: The gas molecules will move from the full container to the empty one until the pressure between the two are approximately equal.The entropy in the empty

container will increase since there will be enough space for the gas particles to move in. If the gas is pushed back into the first container, the entropy will decrease since there will be little space for the particles to move in.

END

INTERVIEW 3
Student: X

125.	I:	What happened in the first demonstration?
126.	X:	I noticed a temperature changed. It decreased. The solution of ammonium nitrate is colder than the reactants.
127.	I:	What about the nitric acid in water?
128.	X:	The temperature of the new solution is a little bit warmer.
129.	I:	What happened when sodium hydroxide is mixed with water?
130.	X:	(The answer not clear due to technical problems)
131.	I:	Why do these reactions you have demonstrated just occur like that?
132.	X:	They react when the conditions are suitable. The molecules of those substances gain kinetic energy and start colliding with one another.
133.	I:	How did they gain kinetic energy?
134.	X:	hmmmm...they just occurred spontaneously.
135.	I:	What do you understand by the word spontaneous?
136.	X:	It is when the reaction occur on its own without addition of some sort of energy. e.g. the energy in a form of heat.
137.	I:	What about the mixture of iron fillings and sulphur powder?
138.	X:	This one is not spontaneous.
139.	I:	How will you make it spontaneous?
140.	X:	By applying heat.
141.	I:	Propane and carbon dioxide are both gases. Which of the two gases will have the highest entropy?
142.	X:	I think it is propane.
143.	I:	Why?
144.	X:	Propane is more denser than carbon dioxide.
145.	I:	Suppose we have gaseous hydrogen in a ten litre container at 25°C. We then heat the container until the temperature reads 50°C. What will happen to the entropy of the gas in the container?
146.	X:	It will increase.
147.	I:	Why does it increase?
148.	X:	The molecules in the gas will start to move and squash against one another, resulting in more collisions thus resulting in higher entropy.
149.	I:	Can you give me an example of a process were entropy decreased.
150.	X:	It decreases in the case of solids. The decrease is from solids to liquids to gases.
151.	I:	Why is the decrease in that pattern?
152.	X:	It is the velocity of the molecules that decreases.
153.	I:	When you mix Kool-Aid drink in powder form with water. What happens to the entropy of the system?
154.	X:	The entropy increases because the kool-aid will react with the water, until when there is a complete dissolution of the powder.
155.	I:	What do you know about free energy?
156.	X:	It is a Gibb's function which is used in calculating energy in voltaic cells.
157.	I:	What is the role played by free energy in chemical reactions?
158.	X:	It is used to make possible the reaction to take place.
159.	I:	How?
160.	X:	I think I have done a mistake.
161.	I:	Where have you done a mistake?
162.	X:	I think is the energy which was used in the whole system.

163. I: Is it all that you know about free energy?
164. X: Yes.
165. I: Do you think that entropy has a role in chemical reactions?
166. X: Yes, It tells us about the nature of the reactants and products. It tells if ever the product will be a liquid or not.

END

INTERVIEW 4

Student M

167. I: What happened in the first demonstration?
168. M: The salt dissolved and the temperature of the test tube dropped. It became cold. The reaction was endothermic. The reactants absorbed energy.
169. I: What did you observe when nitric acid was mixed with water?
170. M: The temperature increased.
171. I: What about sodium hydroxide with water?
(Due to the terrible background noise, it has been difficult to transcribe certain parts of the tape).
172. I: If someone ask you to tell if there will be a reaction between ammonium chloride and sodium hydroxide, how would you respond to this question? You are both outside the laboratory premises.
173. M: I have to know the nature of the reactants.
174. I: What other things could help in solving this problem?
175. M: It is difficult to tell.
176. I: Suppose you have gaseous hydrogen in a ten litre container. The container is at 25°C. The closed container is the heated to 50°C. What will happen to the entropy of the gas and that of the system?
177. M: It will increase.
178. I: Why?
179. M: When the temperature increases, the entropy also increases.
180. I: What other things contribute towards the entropy increase other than the temperature?
181. M: I do not know.
182. I: Why should chemical reactions occur?
183. M: That is when elements react to form compounds.
184. I: Why do certain things occur in a particular direction in nature. E.g. We have body A and body B. Both are metals. Body A is at 30°C and body B is at 20°C. We let body A come into contact with body B in an insulated environment. What will happen between the two bodies.
185. M: There will be a heat transfer from A to B until the temperature is equal.
186. I: Why can't we have the transfer of heat from body B to body A?
187. M: There will be negative numbers.
(He writes an equation: 20 °C - 30 °C = -10 °C)
188. I: What is the meaning of ΔH?
189. M: The energy given out in the form of heat.
For instance they say the reaction is exothermic when heat is given out from the system to the surrounding. Usually we say ΔH is minus.
190. I: When is it negative and why is it negative?
191. M: I think energy decreases when there is a decrease in temperature.
192. I: Which energy decreases?
193. M: It is the energy which was involved in the reaction of the reactants. I think it is the reactants which are at a higher energy state than the products.The energy that they had has been decreased and so it has been released.
194. I: What do you understand by the words, spontaneous reaction?
195. M: It is something that tells us that a reaction has got a natural tendency to

occur.

196. I: Can you give me an example?
197. M: Nitric acid in water
198. I: What about iron fillings with sulphur powder?
199. M: No reaction.
200. I: Can we make it to occur in our life time?
201. M: By heating the container with the mixture.
202. I: Do you agree that non-spontaneous reactions can be made to occur?
203. M: Yes
204. I: Can you give two ways in which you can make non-spontaneous reactions to occur?
205. M: They need energy to make it occur.
206. I: How can you supply it with energy?
207. M: For instance in the form of heat, by using a bunsen burner to heat the reaction container.
208. I: How long will you heat the container?
209. M: It depends on the type of reactants.
Some take a long time to react even though there is heat. They have a long activation energy.
210. I: What is activation energy?
211. M: Lets say you are heating a particular substance, it gains kinetic energy. Its particles gain internal energy. The particles become activated.
212. I: From your view point, why do you think chemical reactions should occur?
213. M: I think it is due to the energy that each of the reactants possess. The energy will cause the substances to react.
For instance, like charges repel. I think there is a force which mix them to react.
214. I: Do you know the name of that force.
215. M: I think it is the internal energy.
216. I: Do you know anything about free energy?
217. M: It is the energy given by the formula $\Delta G=\Delta H+\Delta T$
218. I: What is its role in chemical reactions?
219. M: I am not sure.
END

INTERVIEW TRANSCRIPTS

MOKOPANE COLLEGE OF EDUCATION INTERVIEWS

Interview No. 1

I = interviewer

1.	I	:	What did you observe in experiment 1?
2.	Sipho	:	I observed that the reaction was purely endothermic.
3.	I	:	How do you know that it was endothermic?
4.	Sipho	:	There was a sudden decrease in the temperature on the test-tube. Now meaning that heat has been removed from the surrounding into the system. That is why the test-tube became cooler.
5.	I	:	What did you observe in experiment 2?
6.	Sipho	:	That was purely an exothermic reaction. That is Heat moving away from the system. Liberated heat is used to fill the rise in temperature in the test tube. Meaning that heat had to move away from the system into the surrounding.
7.	I	:	What did you observe in the 3rd experiment?
8.	Sipho	:	This is a question of the change in colour. The first thing that I observed is the change in colour. Sulphur mixed with iron fillings they give a greyish colour.
9.	I	:	What other things did you observe?
10.	Sipho	:	Probably it shows a sort of a reaction between Iron and Sulphur.
11.	I	:	What shows it?
12.	Sipho	:	Okay .... let me just say that it is a heterogeneous mixture of sulphur and Iron fillings.
13.	I	:	Is there a reaction?
14.	Sipho	:	A reaction ..... No.
15.	I	:	From your view point what is a reaction?
16.	Sipho	:	Actually it should be an encounter between two reactants. We should have two reactants encountering one another, whether as an attack or donation of electrons or transfer of electrons.
17.	I	:	Certain reactions are spontaneous and the others are not. What is the meaning of spontaneous?
18.	Sipho	:	A spontaneous reaction ..... I mean by the "word" spontaneous we refer to the capability of a particular reaction to take part without the help of any external factors like heat; .... It means it takes place on itself without applications of external factors.
19.	I	:	What about non-spontaneous reactions?
20.	Sipho	:	Non-spontaneous reactions are those reactions that cannot take place by themselves. They need something to help to initiate the reaction.
21.	I	:	If it initiates the reaction, then what about the rest of the reaction?
22.	Sipho	:	It becomes spontaneous under the action of those factors added to it. In other words..... it means a spontaneous reaction can be spontaneous in one way and non-spontaneous in another way. It depends on the nature of the reacting substances.
23.	I	:	Can you give me an example of a non-spontaneous and spontaneous reaction? If you cannot say it, better write it down.
24.	Sipho	:	Hmm ..... Spontaneous reaction : The reaction between carbon and hydrogen. It is purely spontaneous. In the sense that it also depends on

			the question that the nature of the reacting substances that could contribute to the formation of the ions, now such that hydrogen atoms are attracted to the carbon atom.
25.	I	:	What makes the H's to be attached / or attracted to the carbon atom?
26.	Sipho	:	The electronegativity of carbon. It has to be higher than of hydrogen.
27.	I	:	Is there anything that we can do to cause a non-spontaneous reaction to be spontaneous? Just like the reaction you have just described?
28.	Sipho	:	A non-spontaneous reaction to become spontaneous ..... we can try to provide some heat in order to initiate the reaction. Heat in the form of Hmm.... I mean energy in the form of heat. That is I can heat a test tube and the reaction may now start or show up to be taking place or I may put in a catalyst so as to try to minimise the activation energy, so that they start to react together.
29.	I	:	What can we do to the sulphur and Iron-fillings?
30.	Sipho	:	With sulphur and Iron-fillings, I w .ggest that we heat it. We can heat it for a longer space of time, say 10 seconds.
31.	I	:	When will you know by observation that "NO!!..... our heating is enough"?
32.	Sipho	:	By observation as you are saying ..... After heating this its a question of immediately evaporating dish accumulates heat the reaction will take place. I can heat it and take it away from the flame because it still has heat in it. It has acquired heat, then the reaction will take place. I shall have converted non-spontaneous reaction into spontaneous. (evaporating dish = crucible;) (accumulates heat = means a hot crucible).
33.	I	:	What is the driving force behind spontaneity in chemical reactions? What causes this spontaneity?
34.	Sipho	:	I think spontaneity depends on a number of factors. For instance, in the case of gases, we could ..... it depends on the number of moles of the gas involved in the reaction. It can once more depend upon the ..... as I have said the number of moles of substances. It also depends upon the energy; .... energy changes. Now, - How many do you want?
35.	I	:	To explain this energy changes to me. How does it affect spontaneity?
36.	Sipho	:	I believe by energy change, - take as an example : We have the formula which says the change in energy represent the work plus Q, where Q represent the heat applied. (He then wrote the equation on the paper) $E = W + Q$ Now, this is the work done. Suppose I have a system in a piston, for instance I have my reaction in a piston. We have A + B, they have to react, now what I do believe if I apply work on to the system, where the reaction is taking place. If I apply enough of work, the nature of the reaction cannot be the same as when work is not applied. There is an effect. It can be the effect on the raising kinetic energy of molecules of gas at the side of the pistons. Hence raising the kinetic energy of molecules as you are pressing hard, so the molecules hit the sides of the container, hence increasing kinetic energy.
37.	I	:	How does the increase in kinetic energy affect your spontaneity?
38.	Sipho	:	I think the increase in kinetic energy affects my spontaneity in the sense that immediately there is an increase in kinetic energy, there is an increase in heat and immediately because spontaneity depends upon heat, obviously the reaction may start.
39.	I	:	Okay? According to what you have just explained, is there a relationship between spontaneity and a number of collisions and K_E?

40. Sipho : The relationship between .....?

41. I : You have just said that when there is an increase in K_E the reaction becomes spontaneous.
So, I just want to know if ever you can pick-up any relationship between spontaneity, the number of collisions of your molecules you have just talked about, and K_E of your molecules.

42. Sipho : Ja!.... Let me just start by referring to the number of collisions, as a question of spontaneity. We said, eh..... The number of collisions basically they are based on K_E such that if K_E is very high, the number of collisions per unit area is very high, then actually it promotes as a source of heat, in this sense it promotes spontaneity, but then now the number of moles, as we know that one mole of a gas must occupy a volume of 22.4 cm^3. Now, if I increase the number of moles, in other words, actually this number of moles would like to occupy double the volume of the container, because of an increase in the number of moles such that there is an increase in randomness because it needs to occupy a bigger volume. The spontaneity of a reaction can also be affected by what we call the entropy of a particular substance.

43. I : What is an entropy?

44. Sipho : An entropy is just a change in disorder of a system.

45. I : You said spontaneity can also be affected by entropy. How will entropy affect spontaneity?

46. Sipho : As we talk about the entropy, we have the entropy..... for instance let's take a process where water melts, that is ice, it melts from solid state to liquid state. Now basically there is a change in entropy. An increase in entropy. An ice has too much orderliness in it while a liquid has disorderliness or there is an increase in entropy.
As I am changing from solid to liquid, I am increasing the entropy. Sometimes when you react two different things, say a solid and a gas or liquid, the reaction between a liquid and gas because the entropies of the two are better than the entropy between the ice and the liquid. I believe the one that can be more spontaneous that is, it can occur more rapidly is the reaction between a liquid and a gas, because a liquid and a gas have a higher entropy than a solid and a liquid.
I believe entropy has an effect on the nature of the reactants as we have said that the spontaneous reaction occur without any other external help. Now the nature of the reactants, as a liquid or gas, because they are having an entropy, may help towards improving our spontaneity.

47. I : Do you still have something to say?

48. Sipho : Yes, According to the second law of thermodynamics which talks about the change in the entropy of the surroundings plus the change in the entropy of the system must always be greater than zero. What is means. If I am having the reactants, that is, the system itself. If the entropy of the system becomes higher, there are a number of things involved there. It means, if I increase the entropy of the system I am trying to decrease the entropy of the surrounding. Now going back to the problem of ice and a liquid it needs heat, such that the surrounding will have to lose heat, so that the system will gain in ice. There is a correlation there. The change will actually be greater than zero. For instance, to take it as an example. If I heat water, for it to become a gas, I am changing from a liquid to gas. If I heat water, the liquid, the liquid is getting heat from the surrounding and the surrounding is losing heat such that the number of moles of vapour as the water is becoming vapour now, it gets into the air. now, because it has gained heat. The system gains heat so as to increase its kinetic energy and thus increasing its disorder, that entropy. So an increase in

disorder leads to an increase in spontaneity. They are related.

49. I : You talked about a standard entropy. Can we really use the table of standard entropies to determine that two particular reactants will react spontaneously?

50. Sipho : Actually, what I do believe, it is not only the entropy changes, that can declare that a reaction will be spontaneous, it depends on a number of things. Temperature, some of the reactions seem not to be spontaneous, but if I raise the temperature, there is a stage somewhere, where they become spontaneous. Hence we need to introduce another aspect of determining whether a reaction will be spontaneous or not. That aspect is known as free energy change, the free energy change according to the relationship as determined by the formula,
$G = H - T S$

51. I : Explain this equation to me.

52. Sipho : Ja: In other words, according to these free energy change, we want to look as to what energ changes are happening within the system as heat is applied ..... as w know its enthalpy change according to the tables and there is an increa : n temperature and also a change in entropy. Hence we could determine whether the reaction will be spontaneous or not. For it to be spontaneous, G should be less than O. This depends on the enthalpy change and the entropy change together with the temperature change. Now this should have a special relationship in a system or chemical reaction. Suppose I have those tables on enthalpy change and entropy change, and the reaction is happening at a certain temperature of 298°K. Now as the temperature is there, it is now dependent upon the ..... because this is the ..... it actually shows the temperature, but it can also depend on the enthalpy change of the reaction and also the entropy change. Now I can a sort of try to draw the table to show the relationship how G is dependent on change in enthalpy and change in entropy of the system and also the temperature. We are going to have the enthalpy change, entropy change and G. As we agreed that for us to have a spontaneous reaction G should always be O (less than O), it should be a negative value. If my H is positive, it is endothermic, now it depends on the product of the temperature and a change in enthalpy. Now if my change in enthalpy is..... actually for me to get a negative value, then I shall have my G as negative for all values of temperature.
Now if I have my enthalpy change as negative, and my entropy change as positive, now we go back to the equation itself. What does it suggest? It suggests that I am having the H as negative.
'Suppose I am having both enthalpy and disorder as negative, now I want to look at the nature of my reaction, to tell whether it will be spontaneous or not. Now I will have to look at the relationships. If my H is negative and the entropy change is negative, it will give me a positive value, much that for us to get a difference that is bigger and that is we should have a negative for spontaneous processes, the temperature must have high values. Not only high values of temperature, but it should be values which will account for not having the reaction at equilibrium.

- END/sipho -

Interview No. 2

I = Interviewer
Student = Sophie (S2)

53.	I	:	What did you observe in experiment 1?
54.	S2	:	The reaction has taken place because the solution is more colder than before.
55.	I	:	What did you observe in experiment 2?
56.	S2	:	I observed that the temperature has risen in the reaction between nitric acid with water.
57.	I	:	What did you observe in experiment 3, (iron fillings mixed with sulphur powder).
58.	S2	:	No reaction has taken place.
59.	I	:	Why?
60.	S2	:	Because the temperature remained the same. This is a mixture and not a solution.
61.	I	:	I will be asking the next questions, based on what you have observed. Can you tell me why do certain reactions occur and the others do not occur, just like the examples we have just demonstrated?
62.	S2	:	Other solutions occur spontaneously and the others need a catalyst in order to react with each other.
63.	I	:	Can we use a catalyst in the case of sulphur powder and Iron fillings to make it react?
64.	S2	:	Yes, we should add a catalyst. We should add an acid.
65.	I	:	What will the acid do to the mixture?
66.	S2	:	It will react with Iron-filling.
67.	I	:	You said something about spontaneous reactions. What does the word spontaneous mean; as it is used in chemistry?
68.	S2	:	When we talk about spontaneous reactions we mean that, when we start mixing the two reactants, they just react together immediately without rise in temperature or adding anything to make it happen.
69.	I	:	What are the non-spontaneous reactions?
70.	S2	:	The non-spontaneous reactions need a catalyst to start the reaction.
71.	I	:	How will you determine whether a reaction will be spontaneous or not (without doing experiments)?
72.	S2	:	The nature of the balanced equation.
73.	I	:	How will the balanced equation guide you?
74.	S2	:	If the enthalpy and the disorder are positive and the free energy is negative, then the reaction will be spontaneous. If the free energy becomes positive, then the reaction will be non-spontaneous.
75.	I	:	What about the "disorder".
76.	S2	:	There is an increase in disorder in a spontaneous reaction. In a non-spontaneous reaction there is no disorder. If the enthalpy is more than the disorder, then the free energy will be positive. If the enthalpy is less than the disorder, then the free energy will be negative.
77.	I	:	What do you understand by the word "Enthalpy"?
78.	S2	:	It is the heat transferred from the system to the surroundings.
79.	I	:	How can you represent it symbolically?
80.	S2	:	She wrote : (H)
81.	I	:	What do you mean by saying the "disorder" of the system? You talked about this.
82.	S2	:	Disorder means ..... When the disorder happens, it means that the molecules in a substance have more kinetic energy.
83.	I	:	Is it all about the disorder? Okay? What is the role of the "disorder" in a spontaneous reaction?
84.	S2	:	(She remains silent for a long time.)
85.	I	:	What is this free energy you spoke about lately?
86.	S2	:	Free energy is the energy lost by the system.

87. I : When is it lost?
88. S2 : When the reaction is taking place the free energy is taken out?
89. I : How is it taken out?
90. S2 : It is no more necessary ..... it is not used when the two substances react.
91. I : Suppose we have the two gases, carbon dioxide and propane. Which of the two gases will have the greatest entropy under standard conditions? (The interviewer then wrote down the molecular formulae of the two gases.)
92. S2 : Propane will have the greatest entropy.
93. I : Why?
94. S2 : Because the compound is larger than carbon dioxide.
95. I : What do you think could be contributing towards this great entropy?
96. S2 : Because the molecule is large, when there is disorder, it will occupy large space or volume.
97. I : Suppose we have 1 mole of hydrogen gas in a 10 l container at 25°. We then heat the container. The temperature rises, but the volume remains unchanged. So, what will happen to the entropy of the system?
98. S2 : The entropy will increase.
99. I : Why?
100. S2 : Because of the increase in temperature.
101. I : How does the increase in temperature affect this increase in entropy?
102. S2 : The system absorbs heat and that increases the entropy.
103. I : Can we make the reactions which fail to occur normally to be spontaneous?
104. S2 : Yes.
105. I : How?
106. S2 : By using a catalyst, or by increasing the concentration of the reactants.
107. I : Suppose we have two bodies, A and B. A is at 40° and B at 20°C. We let the two bodies come into contact with one another. The system is insulated.
What will happen between the two bodies?
108. S2 : Because A is hotter than B, there will be a change in temperature between A and B. A will decrease and B will increase in temperature until they all have the same level of temperature.
109. I : How will you know that they are at the same level of temperature?
110. S2 : The two bodies are now at equilibrium.
111. I : Is it possible that heat can be transferred from body B to body A.
112. S2 : Not possible.
113. I : Why?
114. S2 : Because there is less kinetic energy in the cold body. It will be the heat that will travel from the hot body and not from the cold body.

-END-

Interview No. 3

Student = Gregory (G)

115. I : What did you observe in the first experiment?
116. G : As the reaction continued, the outside of the test-tube felt even more colder. I think in this case the heat is taken into the system.
The reaction is endothermic.
117. I : What did you observe in experiment 2?

118.	G	:	The beaker became hotter. So, in this case the system was releasing heat suggesting that it is an exothermic reaction.
119.	I	:	What did you observe in the 3rd experiment?
120.	G.	:	There is no reaction.
121.	I	:	Why?
122.	G	:	Because, if I can get a magnet, I may easily extract the iron-fillings from the mixture.
123.	I	:	From your viewpoint what is a reaction?
124.	G	:	It is a process whereby the reactants mix to form a compound. The components of the compound cannot be easily separated.
125.	I	:	You spoke about exothermic and endothermic reactions. What are exothermic reactions?
126.	G	:	Exothermic reactions release energy.
127.	I	:	Endothermic reactions?
128.	G	:	Endothermic reactions absorb energy.
129.	I	:	What happens during an exothermic reaction?
130.	G	:	I think an exothermic reaction is spontaneous.
131.	I	:	What are spontaneous reactions?
132.	G	:	I think it is the reaction which takes place without any external force. They just occur without any addition of energy to start a reaction.
133.	I	:	What about non-spontaneous reactions?
134.	G	:	Non-spontaneous reactions are reactions which do not proceed on their own. Something like energy need to be added to the system.
135.	I	:	Can you give me an example?
136.	G	:	The mixture of iron fillings and sulphur. Unless something is done to the components of the system, nothing will take place.
137.	I	:	What is that "something" that you can do to this mixture of iron-fillings and sulphur to make it react.
138.	G	:	I think, even if I am not sure, heating the mixture would do.
139.	I	:	Besides heating, what else can we do to make non-spontaneous reactions occur?
140.	G	:	Add a catalyst.
141.	I	:	How can a catalyst make it to react.
142.	G	:	The catalyst is used to speed up the reaction. I am not sure if ever the catalyst can initiate a reaction in the case of non-spontaneous reactions.
143.	I	:	What other theoretical quantities can tell us that a reaction will be spontaneous. (No experimentation is necessary at this point.)
144.	G	:	The so called change in free energy can either tell us that a reaction will be spontaneous or non-spontaneous. That is when the change in standard free energy is negative, the reaction will be spontaneous. Then when change in free energy is positive the reaction will be non-spontaneous.
145.	I	:	What is this free energy you are speaking about and where do we get it from?
146.	G	:	I think it is the energy which has not been used to cause the reaction to proceed.
147.	I	:	Is this free energy the only factor that determines the spontaneity of a reaction?
148.	G	:	The entropy of the reaction can tell us if the reaction will be spontaneous or not. When change in entropy is positive, the reaction is spontaneous and when it is greater than zero, the reaction is non-spontaneous.
149.	I	:	What is this entropy?
150.	G	:	The state in which substances change from an orderly state to a disordered state.
151.	I	:	What is the role of orderliness and disorderliness in chemical reactions?

152.	G	:	This disorderliness makes it possible for certain compounds to dissociate. The orderliness helps in the formation of products.
153.	I	:	Is there any other role of entropy except the one you have just mentioned?
154.	G	:	I cannot remember anything.
155.	I	:	Can you write down the equation to explain changes in free energy in a system and surroundings?
156.	G	:	(He wrote delta G = delta H - T delta S.)
157.	I	:	Can you explain this equation to me? What does it mean?
158.	G	:	G stands for change in free energy. H stands for change in enthalpy. T = is constant temperature. S stands for a change in entropy.
159.	I	:	If the temperature is constant, which values change here.
160.	G	:	If the temperature is constant, only the values of G, H and S change.
161.	I	:	Can you vary the changes to show me that you understand that if you change enthalpy, for example, what would happen to the value of entropy and the value of free energy change. Say for instance your enthalpy is positive.
162.	G	:	If enthalpy is positive ..... I think the chances of spontaneity will not be favoured.
163.	I	:	Why?
164.	G	:	Because if enthalpy increases to positive value, meanwhile the entropy remain unchanged or constant. This can make G attain a positive value. Which means the reaction will be non-spontaneous.
165.	I	:	Suppose we have 1 mole of hydrogen gas in a 10 l container at 25°C. We heat the container of 1 mole of hydrogen gas to 50°C at a constant volume. What will happen to the entropy of the gas?
166.	G	:	I think the entropy of the gas will increase due to the fact that as more of these gas molecules are heated, the average kinetic energy of the molecules increases, resulting in more and more disorderliness of the hydrogen gas. This can be seen by the pressure increasing meanwhile the volume is constant.
167.	I	:	Carbon dioxide and propane are both gases. Which of these two gases will have the greatest entropy under standard conditions?
168.	G	:	Silent for a while.
169.	I	:	Okay ..... Hmm, can you write down the molecular formula of these two gases?
170.	G	:	Yes, CO_2 and CH_3 CH_2 CH_3 (this is what he wrote).
171.	I	:	Which of the two gases will have the greatest entropy?
172.	G	:	I think carbon dioxide will have the greatest entropy because it is a small molecule as compared to propane, which is a large molecule. The carbon dioxide particles will keep on rising.
173.	I	:	Why do you think certain reactions would occur and others do not occur?
174.	G	:	I think this ..... I am sorry, I cannot predict the answer here.
175.	I	:	Why do you think from your point of view, should chemical reactions occur?
176.	G	:	Without chemical reactions, I do not think the production of chemicals would be possible.
177.	I	:	From your viewpoint, what is the main reason that we should have chemical reactions occurring between substances? Remember, certain reactions are natural.
178.	G	:	In nature reactions do occur. Biochemical reactions occur naturally. If biochemical reactions were not there, I do not think that we will be able to survive.
179.	I	:	So, what causes these biochemical reactions to occur?

180.	G	:	I think the co-enzymes are the main factors which cause this to occur.
181.	I	:	Is there any other thing that you would like to add?
182.	G	:	Nothing.
183.	I	:	We have two bodies, A and B. The bodies have the same size, made of the same material. Body A is at a temperature of 40°C and body B at a temperature of 20°C. The two bodies are made to come into contact with one another. (A demonstration was necessary at this stage.) The two bodies are insulated. What do you think would happen to the two bodies?
184.G	:		Eh ..... I think some of the heat will be transferred from body A to body B.
185.	I	:	Can body A give body B all of its heat?
186.	G	:	No..... The transfer of heat will occur until the two bodies have an equal amount of heat.
187.	I	:	Can we have body B giving body A some units of heat?
188.	G	:	No?
189.	I	:	Why?
190.	G	:	Body B is having a less amount of heat than body A. So I do not think it is possible for some of the heat to be transferred from B to A.
191.	I	:	Why do certain processes follow a particular direction when they occur? For example, the previous problem of the two bodies involved in heat transfer.
192.	G	:	In the case of chemical reactions, if there is more concentration of the products, the direction will be towards the formation of the reactants. If the concentration of the reactants is too high, will have the direction of the process shifting to the formation of the products.

INTERVIEW No: 4 and 5

Students: Lawrence (L) and Johannes (J)

[The two students had to be interviewed together because they wanted to join their fellow students who were outside - on strike. They felt that they were not safe and would be intimidated by their fellow students, thus they were impatient]

193.	I	:	What happened in the first demonstration when we mixed ammonium chloride with water?
194.	L	:	The test tube became very cold. That means the reaction has taken place, but I think since the test tube was cold, the reaction was slow. In the experiment were nitric acid reacted with water the test tube became hot. So that means the reaction became very fast compared to the first one.
195.	J	:	When I added ammonium chloride to water the test tube became cold. That means the reaction absorbed energy from the surrounding. When nitric acid reacted with water the test tube became hotter indicating that energy has been given off to the surrounding. The reaction was exothermic.
196.	I	:	Lawrence, what can you say about the third experiment. Iron fillings and sulphur powder?
197.	L	:	No reaction. It is just a mixture.
198.	I	:	Why?
199.	L	:	No it is a reaction because I cannot take out sulphur from the iron fillings.
200.	I	:	What type of a reaction?
201.	L	:	I should think it is endothermic.
201.	I	:	What makes you to think that it is endothermic?
202.	L	:	Because if it was exothermic, the first thing I will observe is I will see that energy is released due to the hotness of the cup on this thing I have left it. since it is cool it is endothermic. that means it just absorbing energy from

			the outside.
203.	J	:	To let sulphur react with iron fillings completely I think a catalyst should be added even water. A catalyst or heat. This experiment need a catalyst to become a homogeneous mixture. You can see that this is a heterogeneous mixture. For it to be a homogeneous mixture it need a catalyst something like heat for it to happen. Then it will be a spontaneous one.
204.	I	:	How long are you going to heat the mixture?
205.	J	:	You heat it until the equilibrium is reached.
206.	I	:	When will you know that an equilibrium is reached?
207.	J	:	I should think when the ingredients have been mixed homogeneously
206.	I	:	Why do chemical reactions occur?
207.	J	:	It occurs when the reactants have the energy sometimes the energy of the reactants can be low in such a case the reaction cannot take place rapidly. It means that the activation energy should be added. For a reaction to take place there should be energy available.
208.	L	:	Two substances, these reactants are different in energy so some they transfer their electrons to one another to form a reaction. That means energy causes reactants to occur so that we ultimately have a reaction
207.	I	:	How does the energy cause the reactions to occur, Lawrence?
209.	L	:	These happen because the substances reacting are different, some have the ability to donate some have the ability to accept. So if a substance can donate electrons the other one will accept them and as such there will be a reaction.
210.	I	:	What about you energy now. You spoke about energy.
211.	L	:	The energy I am talking about I think it is just the transfer of electrons from one substance to another.
212.	I	:	Certain reaction occur naturally while others do not. What do we call the reactions which have a natural tendency to occur?
213.	L	:	I will call them spontaneous reactions because they just occur spontaneously without being fast or slow. Not all of them are fast. Some are slow but with the aid of a catalyst they can be fast.
214.	I	:	What are the non-spontaneous reactions?
215.	L	:	The reactions that cannot occur by the natural tendencies.
216.	I	:	Johannes, what are spontaneous and non spontaneous reactions?
217.	J	:	Non spontaneous reactions are the reverse of the spontaneous reactions. I should think they are the ones that need more energy to happen or occur and then again non-spontaneous reactions depend on the reactants themselves. Another reactant may not have energy whereas another reactant may have energy or both reactants may not have energy the reaction may not be spontaneous because the reactants do not have energy. For us to get the reaction to be spontaneous we have to activate the reactants.
218.	I	:	How can you determine that a reaction will occur?
219.	J	:	The nature of the reactants, for example if I know that I am having sulphuric acid and again I should know how dangerous sulphuric acid is, together with other substances. Right, if I may use theoretical quantities to write a reaction so that I see the products. From the nett reaction I have written down I will detect that this reaction can occur or it cannot occur under certain conditions.
220.	L	:	What he has said I think it is correct. And then I will refer back to some concepts that says like react with like. For example water dissolve ethanol. The thing is we will have a homogeneous mixture. We are concerned with the results, products that a reaction will give. I should think it depends on the nature of the reactants themselves.

221.	I	:	What other quantities can help you to predict if a reaction will take place spontaneously?
222.	J	:	I should think it is the table for the change in energy, the change in Gibb's energy and the enthalpy and the measure of the disorder in the system and the temperature too. those are the determining factors to tell us wether a reaction will occur or not.
223.	I	:	How will you use these factors?
224.	J	:	For a reaction to occur the Gibb's energy I should think is less than zero. When ever we have a negative value of the change in G it means that the reaction will occur. The temperature in that sense should be negative. It should be low not necessarily negative for the reaction to occur.
225.	I	:	What about you Lawrence?
226.	L	:	The periodic table can help us a bit. On the periodic table we know that we have got elements of group 1, 2 and so on. If we take halogens, we know that they are always in need of one electron to complete the energy level. The substance under halogens has got the ability to react with other elements which can be attracted to it to share the electrons. The electronegativity is also important.
227.	I	:	Johannes, can you write the equation showing a free energy change?
228.	J	:	T is the symbol for temperature, change in S is the measure of the order of the system, change in H is the energy of the reactants and then G is the energy of the whole system.
229.	I	:	What is free energy?
300.	J	:	It is G
301.	I	:	What is its role in the reaction?
302.	J	:	I should think it in this fashion, for the reaction to be spontaneous the free energy should be less than zero. It means the energy of the system should be less. We must have less energy. If we have a high free energy it will affect the order of the system. Its role I can say is to cause the disorder in the system.
303.	I	:	When you have the disorder in the system - what happens?
304.	J	:	The system will continue in disorder until that energy or the equilibrium constant is reached.
305.	I	:	What does delta S stand for?
306.	J	:	The measure of the disorderliness of the system. Its role is to show us wether the system will be in order or disorder or the nature of the disorder of the system.
307.	I	:	Yes, Lawrence explain the equation of free energy to me.
308.	L	:	This delta S we call it enthalpy which is the measure of the disorder of the reaction. And the T is the temp under which the reaction take place. Right, this delta G is the free energy . From this delta G we can detect three things. If we find that delta G is negative then the reaction is spontaneous. Again if this free energy is zero it means the reaction is in equilibrium. If the free energy is greater than zero it means the reaction is non-spontaneous.
309.	I	:	How can you make non-spontaneous reactions to be spontaneous?
310.	L	:	I will increase the temperature or the enthalpy. There will be more value here (delta H - T delta S),therefore making the delta G negative.
311.	J	:	We have this idea that for a spontaneous reaction the delta G must be negative. Then when it is at zero the reaction is at equilibrium. If delta G is positive the reaction will be non-spontaneous. For us to make this spontaneous we must have delta G less than zero. This can be done by increasing the temperature of the system or by increasing delta S or the disorderliness of the system.
312.	I	:	What do you mean when you say you will change the disorderliness of the

system?

313. J : By means of applying heat.

314. I : Is there any other way you can use other than applying heat?

315. J : No

316. I : Suppose we have one mole of gaseous hydrogen in a 10 litre container at 25 C. We then heat this container to 50 C. What will happen to the entropy of the gas?

317. L : Since we have increased the temperature, this implies that the entropy is going to increase causing more disorder of the reaction.

318. I : Why does the entropy increases?

319. L : It increases because we have increased the temperature of the reaction.

320. I : Which entropy increases, is it the system or reaction?

321. L : I think it is the entropy of the substance, hydrogen gas.

322. I : What about you, Johannes?

323. J : The entropy of the gas will increase because we have increased the temperature of the hydrogen gas which is inside the container. Again we have this concept that says molecules or particles of a gas are always in a constant motion. When ever you are increasing the temperature they will be moving in a high constant random motion and the kinetic energy will be increased because of the equation that says $K_e = 1/2\ mv^2$. The velocity will be increased and we will be having more pressure in the container.

324. I : Carbon dioxide and propane are both gases. Which of the two will have the greatest entropy at room temperature if we have their amount equal?

325. J : It is carbon dioxide. We are concerned with the number of carbon atoms in the compound. Propane has more number of carbon atoms again it is a bigger structure than carbon dioxide. At standard temperature and pressure conditions, carbon dioxide will have more entropy than propane because of its size.

326. I : How does the size of a molecule affect its entropy?

327. J : In fact whenever we are increasing entropy we are causing the disorder in a system.

328. L : I am not sure

329. I : Body A and body B are at two different temperatures. the two bodies are then made to come into contact with each other. S what will happen between the two bodies?

330. J : The two bodies will have the same temperature.

331. I : How do you know?

332. J : There will be heat transformation. The energy or the temperature of body A will be transferred to that of body B and the temperature of body B will be transferred to body A because of the concept that says energy can never be created or destroyed but can be changed from one form to another. It means they will be having the same energy or temperature.

333. I : What is happening in the two bodies when heat is being transferred?

334. J : I should think the body with the lower energy it has to retain the higher energy of that other substance,so that they ultimately they will have equal energy.

335. I : What energy is that?

336. J : Heat of-course in this case. The other body at 40 C and the other one at 20 C. In order to combine the two bodies this body B should absorb energy from body A so that they ultimately have the same heat.

337. I : Can body A transfer all of its energy to body B?

338. L : No

339. I : Why?

340. L : This is a matter of heat transformations. They try to maintain the temperature of each other. In this case another one cannot be left at a

higher temperature than the other one. They try to balance their heat energy.

341. I : You Johannes?
342. J : As Lawrence has said.
343. I : Can we have body B giving body a some heat energy?
344. J & I : No
345. I : Why?
346. L : It lacking energy, 20 C to be at the same level with body A. It means that the temperature from A should be moved to the temperature of body A but body B can do it.

- END/ Johannes and Lawrence -

INTERVIEW *6*

STUDENT: RONNIE

(The first part of this interview was not clear for transcription due to some technical problems with the tape recorder.)

347. R : As you can see, ice is in a solid state. It is in an orderly state. So if I apply heat to the system, the intermolecular forces will be weakened. We are going to have the substance in a liquid form. The intermolecular forces will be less meaning that the molecules are now free to move because there is an increase in entropy. Change in entropy is increasing because of the increase in temperature which weakens the intermolecular forces that bind the water molecules in the solid state. In this case, in the reactions of this nature, it is where I can illustrate the change in entropy.
348. I : What about if you had a liquid and a liquid reacting? e.g. nitric acid mixed with water?
349. R : In this case They are separate materials in this case. I can say they are also at a higher entropy from the start. There was a rise in temperature but no body applied that temperature. It comes from the reactants themselves. The reactants were at a higher energy. Thus why the test tube was hot. The products were at a lower energy than the reactants. I can say that the products were at a lower entropy.
350. I : Suppose we have one mole of nitrogen gas in a 10 litre container at 25 degrees Celsius. We then heat the gas in the container to fifty degrees Celsius. The volume remains constant. *What will happen to the entropy of* your gas?
351. R : First let me address my attention on the container. When you are talking about the entropy, you are talking about the disorder of the system. The entropy will not change in this case since it does not have a role here. For the entropy to change it means the volume must change so that the molecules of the gas are free to move. Since the temperature of the system increased I believe that only the internal energy of the system will increase. This will not affect the randomness of the particles since the volume is constant. Entropy will also be constant.
352. I : Can you explain why your entropy remains constant?
353. R : Well I do not think I will explain anything further.
354. I : Why do certain reactions occur naturally and other do not occur?
355. R : I may just give some examples. Lets talk about sand plus water. Sand is not miscible with water. The atoms of sand are so bound to form a compact structure that is rigid.
356. I : What makes the sand and the water not to react?

357.	R	:	Because the sand is rigid.
358.	I	:	What makes a reaction to occur?
359.	R	:	A solvent is able to weaken the forces that bind a particular material. But in the case of sand and water, water cannot penetrate the particles of the soil because of its compact structure. In the case of ammonium chloride with water, water succeeded in weakening the intermolecular forces of ammonium chloride.
360.	I	:	Can an enthalpy tell us that a reaction will be spontaneous or not?
361.	R	:	It can tell us.
362.	I	:	How?
363.	R	:	If I want to relate it with the equation for which it is included. I think it can tell us something.
364.	I	:	You have body A and body B. The bodies are all made of steel. Body A is at 40 degrees celsius and body B at 20 degrees celsius. The two bodies are made to come into contact with each other. What will happen between the two bodies A and B?
365.	R	:	Heat will eventually flow from body A to body B. They will eventually reach an equilibrium state where they will have equal temperatures. If it does not loose anything we are going to have the system having 60 degrees Celsius. We do not have any external factor which absorbs this heat. We are talking about the sum of the temperatures. The combination of the two temperatures.
366.	I	:	Somewhere you said that they will reach a temperature equilibrium. How will you know that equilibrium is reached?
367.	R	:	If I can use a thermometer. - END/RONNIE -

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