CHAPTER 2

REVIEW OF RELATED LITERATURE

2.0 Introduction

Diffusion and Osmosis are considered two topics that students' find difficult to understand in Biology. A number of research investigations have described students' alternative conceptions about diffusion (Simpson & Marek, 1988; Westbrook & Marek, 1991) and osmosis (Zuckerman, 1993).

The objectives of this study were to investigate and identify the difficulties faced by selected Form Four biology students in understanding the topic of diffusion and osmosis. This study will ascertain the common and recurring alternative conceptions of diffusion and osmosis for seven concepts and also ascertain whether formal reasoning ability and gender have any effect on this understanding. In this regard, the review of literature covers the following areas:

(i) Students conceptions in science

(ii) The two-tier multiple choice diagnostic test

(iii) Students' conceptions in diffusion and osmosis.

(iv) Formal reasoning ability and science achievement.

(v) Gender and science achievement.

2.1 Students' Conceptions in Science

Students' conceptions in science refer to students' views of the world which they acquired before or after they have been formally taught in science. Many research studies have revealed that students' views of the world are very much different form the scientists' views and such views were difficult to change.

Osborne and Freyberg (1985) summarized the nature of students' conceptions in science as follows:

(i) Prior to any teaching and learning of formal science, students develop meanings for many words used in science teaching. Students, too, have their own views of the world which relate to ideas taught in science.

(ii) Students' views of the world are strongiy held by them, and are usually different from the views of scientists.

(iii) From students' point of view, their own views of the world are sensible. These views are difficult to change and often remain uninfluenced by science teaching.There are differences between students' views and scientists' views of the world.

Osborne, Bell and Gilbert(1983) summarized the differences between students' views and scientists' views as follows:

(i) Students tend to view things from a self-centred and human-centred point of view. Students only consider words and events in terms of human experiences and values. Scientists are capable of abstract reasoning and they are able to conceptualise items and events which are of no observable instances.

(ii) Students are more interested in simple explanation for things that occur in their familiar world because of their limited experience. Scientists, on the other hand, need to use abstract conceptions and theories in their explanations and predictions of events.

(iii) Many of the words that students used everyday have meanings which are different from those used by the scientists because students do not need precision for the language used.

According to Gilbert (1982), there are five possible outcomes when students' conceptions in science interact with teachers' teaching in the classrooms. These five possible outcomes are:

(i) Undisturbed Students' Science Outcome

- Students' viewpoints appear to be influenced by formal teaching. Ideas taught in the class have no impact on the students' conceptions, with respect to certain situation.

(ii) Two Perspective Outcome

Teacher's viewpoints are rejected but students still consider such viewpoints as something that must be learnt for certain purposes. Therefore, the students have two views of an event but the science viewpoint acquired is not the one that is to be used outside the class.

(iii) Reinforced Outcome

Students' prior conceptions are maintained but reinforced by teacher's teaching in the explanation of a particular viewpoint.

(iii) Mixed Outcome

Students' views are a mixture of students' own conceptions and teachers' teaching. These ideas are interrelated in many different ways. As a result, students have ideas that are not integrated and may be self contradictory.

(iv) Unified Scientific Outcome

Students acquired the scientific concepts which they understand and appreciate, and these concepts can be related to the environment in which they live and work.

Students have been found to possess their own views of the world and meanings for words which are uninfluenced by formal teaching. Very often, students tend to misinterprate, confuse and reject the scientific views presented to them.

Posner, Strike, Hewson and Gertzog (1982) have suggested that, if students are to change their own ideas, they must first find their own ideas unsatisfactory. This requires well-planned learning experiences which will highlight to the students the inadequacies present in their ideas. Besides, the students must be accessible to new ideas which are easily understood by them.

According to Posner, Strike, Hewson and Gerrtzog (1982), the new idea must be:

(a) intelligible, in that it appears coherent and internally consistent;

(b) plausible, in that it is reconcilable with other views that the students already have and

(c) fruitful, in that it is preferable to the old ideas on the grounds of perceived elegance, parsimony and usefulness.

2.2 The Two-tier Multiple Choice Diagnostic Test

Multiple-choice diagnostic test is basically a paper-and-pencil test comprising of a number of relevant items. The alternatives for an item in the test are usually prepared based on students' answers to essay question and other open-ended questions because ' these alternatives being representative of typical conceptions and misconceptions of students have a distinctive advantage as compared to regular test items for which professional test writers provide the alternatives'.

The common methods for assessing students' misconceptions using interviews and/ or open-ended questionnaire require too many investigators involved in large amount of time to carry out the interview with so many students.

In addition, substantial training of so many investigators is also a problem. A straightforward method to overcome these difficulties would be to administer a pencil and paper multiple choice test (Treagust & Haslam, 1987).

Treagust(1985) described a development of a two-tier diagnostic test to measure students' idea. The first tier of each item is a multiple choice content question which relates to prepositional statements and parts of the concept map. The second tier of each item is composed of a multiple choice set of reasons for the answer related to the first tier. The set of reasons includes the scientific answer and possible misconceptions held by students.

Diagnostic multiple-choice tests can be immediately scored and hence they are useful diagnostic tools for teachers to easily ascertain students' conceptions. The procedure in the development of the two-tier multiple-choice test included the following stages:

(i) defining the scope of the target conceptions in terms of propositional statements and concept maps representing the knowledge required to understand the scientific concepts;

(ii) developing a paper-and-pencil test consisting of open-ended items and administering to high school students;

(iii) analyzing the students' responses to identify the commonly occurred misconceptions and interviewing of the students in case further explanation and clarification are needed;

(iv) constructing a two-tier multiple choice test items based on the most commonly identified responses that students answered in open-ended questionnaire and follow-up interview.

In the two-tier multiple choice test instrument, the first tier of each test item consists of a content question asking students to predict the outcome of a situation and usually providing several distractors along with the correct answer. The second part asks for a reason for their answer in the first part. The reasons provided for students to choose contain the correct answer and possible misconceptions identified in questionnaire and interview studies..

Treagust (1988) suggested three broad areas in which a multiple-choice Diagnostic test can be developed. The three areas are the identification of content areas, the collection of information about students' ideas and the development of the diagnostic test.

In the identification of content areas for the test, the following steps are involved:

(i) identifying propositional knowledge statements;

(ii) developing a concept map;

(iii) relating propositional knowledge to the concept map; and

(iv) validating the content.

In order to obtain information about students' ideas of a concept, Treagust (1988) suggested the following three steps:

(a) a thorough examination of the relevant literature;

(b) interviews with students about their understanding of the concept; and

(c) obtain responses from open-ended questions in paper- and-pencil test.

The multiple-choice diagnostic test is finally developed to consist of items comprising two parts: the first part of each item is a multiple-choice question concerning a particular content area while the second part of each item is a multiple-choice set of reasons for the answer given in the first part.

The test developed, is subjected to continuing refinements to ensure that it can be used effectively for detecting students' ideas. A two-tier diagnostic test is developed from the multiple choice items with a design comparable to the format of the 'Test of Logical Thinking' by Tobin and Capie, (1981). The first part of each item on the test is a multiple choice content question having usually two or three choices.

The second part of each question contains a set of four possible reasons for the answer given to the first part. The reasons misconceptions, together with simple wrong answer if needed. This second part of item in the test is developed from the students' responses on the reasons given to each response question as well as information gathered from the interviews and the literature.

For the purpose of this study it was be appropriate to use the diffusion and osmosis diagnostic test(DODT) because of its two-tier multiple-choice format. The diagnostic test would enable the researcher to detect the students alternative conceptions in the seven concepts assessed in this study.

2.3 Students' Conceptions in Diffusion and Osmosis

There have been several studies that have explored the difficulties students have with learning diffusion and osmosis.

Odom (1995) administered the Diffusion and Osmosis Diagnostic Test (DODT) to 116 secondary biology students, 123 college non-biology majors, and 117 biology majors. Misconceptions were detected in five of the seven areas measured by the test: the particulate and random nature of matter, concentration and tonicity, the influences of life forces on diffusion and osmosis, the process of diffusion and the process of osmosis. There was no significant difference found between secondary and non-biology majors' understanding of diffusion and osmosis concepts. However, there was a significant difference between biology majors and secondary/non-biology majors.

According to Westbrook and Marek,(1991), even motivated students are plagued by misconceptions.7th grade, 10th grade and college level students were tested after being introduced to the concept of diffusion through reading, lectures and writing activities. It was found that none of the 300 participants who participated in the study had a clear understanding of diffusion. The researchers noted that even though base knowledge increased, there was also an increase in their misconceptions, especially the misuse of technical terms. Some examples of the misconceptions students had at various grade levels are provided below:

> "…..The dye will soon disappear because when a liquid substance meets another liquid substance they combine and become one." (7th grade)
>
> "…..The dye will be 'spread' out so widely that it will completely 'disappear'." (10th grade)
>
> "…..It (dye) will dissipate and most likely not be detectable visibly unless the dye is extremely potent." (college level)

When many of the incorrect responses were reviewed, it became apparent that all the students' exhibited an inability to grasp the abstract nature of diffusion and this misunderstanding denied them the opportunity to obtain a complete understanding of diffusion and osmosis concepts.

It was also discovered that specific misconceptions were found across grade levels. It was detected that increase in molecular knowledge, did not increase the understanding of diffusion and osmosis concepts. According to Westbrook and Marek, (1991), many students use incorrect terminology when explaining scientific events Westbrook and Marek, (1991).

According to Marek, Cowan and Cavallo, (1994), students have many erroneous thoughts on diffusion and osmosis processes. They further explored the idea that concrete learners acquired misconceptions about diffusion and osmosis easier than formal learners. It was apparent that many of the principles of diffusion and osmosis were being taught at the formal operational level to predominantly concrete operational students.

Subject matter should be introduced to students in a manner that permits them to gain an accurate and working understanding of the finite principles of diffusion and osmosis. In the Piagetian model, disequilibrium occurs when the details the student has gathered conflicts with existing mental structure.

Disequilibrium is the driving force in the learning process and demands a choice on the part of the learner whether to ignore the new data or resolve the conflict Westbrook and Marek, (1991). When students discover connections between related topics for themselves then they experience an ownership of the new idea.

When they have this experience, they may release the old ideas and replace them with newly modified ideas. Students should be permitted to voice their decisions and defend their positions on a topic through open discussions. These discussions also develop social skills and awareness of other views. After students have absorbed the new ideas, they can begin applying them to other topics Marek, Cowan and Cavallo, (1994).

Unfortunately , some students will persist in holding on to their alternative idea and make the new information fit into their mental framework making future learning even more difficult Westbrook and Marek, (1992).

If concrete operation students are being taught formal operations ideas through lecture only, most high school students will only memorize the facts and provide them on the test with out comprehension in order to make an acceptable grade.

Memorization of isolated pieces of information that students do not understand logically leads to misconceptions Westbrook and Marek, (1992). Since diffusion and osmosis concepts are very complex and are the basis for many biological and chemical processes, initial misconceptions tend to grow larger when new materials are introduced. Memorizing facts rather than comprehension of basic concepts creates a vicious cycle that is very difficult for teachers and students to curtail.

Zuckerman (1993) identified i2 accurate conceptions and 8 inaccurate conceptions about osmosis held by high school science students. She reported that misconceptions about osmosis blocked problem solving of osmosis-related questions. Of the 12 accurate conceptions, two were especially important in enabling problem solvers to generate correct answers that is the rate of osmosis is constant; the concentrations of water across the membrane must be equal at osmostic equilibrium.

According to Westbrook and Marek (1991), diffusion is a concept that crosses the disciplinary boundaries of chemistry and biology, and is an excellent concept for use in a cross-age study of student understanding . Instruction of the concept of diffusion begins in grade seven and recurs in most life science and physical science courses in high school and early college.

Diffusion is easily demonstrable in the classroom and is readily experienced in the student's everyday life. A thorough understanding of the concept, however requires an inability to conceptualize the molecular events governing the process.

Prior research involving the concept of diffusion indicated that students have very little understanding of the concept. According to Friedler, Amir and Tamir (1987), there are several reasons why we should focus on osmosis in science or biology teaching:

(i) Osmosis is a key concept for understanding many important life processes for example water intake by plants, water balance in land and aquatic creatures, transportation in living organisms and consequently it is studied repeatedly over the school years in a variety of contexts.

(ii) The concept of osmosis is closely related to key concepts in physics and chemistry example diffusion, permeability, solutions, particulate nature of matter.

(iii) Experience has shown that the topic is difficult, probably because of the demand for abstract reasoning and the dependence of the process on many factors.

Johnstone and Mahmoud (1980) discovered that 'osmosis and water potential' were regarded by students and teachers as the most difficult of fifteen major biological concepts. Why should the osmosis topic prove to be so difficult? Several reasons are cited in the literature:

(i) The student has to learn and use several underlying new concepts such as diffusion, plasmolysis, turgor, selective membrane

(ii) Some of the prerequisite concepts require knowledge of physics and chemistry example solutions, solubility, solute, concentration, dilution, particulate nature of matter were found to be difficult, especially for biology students.

(iii) The confusing use of terms by textbooks and teachers example diffusion pressure deficiency and water potential.

(iv) Confusion is caused by the difference between the everyday meaning and the scientific meaning of concepts example pressure, concentration-quantity.

(v) The tendency of teachers and students to use teleological explanation example 'the water moves out in order to balance the concentrations (Friedler, Amir and Tamir, 1985).

A study conducted by Odom and Barrow(1995) involved the development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. Misconception data were collected from interviews and multiple-choice questions with free response answers.

The data were used to develop 12 two-tier multiple choice items in which the first tier examined content knowledge and the second examined understanding of that knowledge. The conceptual knowledge examined was the particulate and random nature of matter, concentration and tonicity, the influence of life forces on diffusion and osmosis, membranes, kinetic energy of matter, the process of diffusion, and the process of osmosis.

The Diffusion and Osmosis Diagnostic Test (DODT) was administered to 240 students (123 non-biology majors and 117 biology majors) enrolled in a college freshman biology laboratory course. Twenty misconceptions (Table 2.1) were detected in five of the seven conceptual areas through analysis of items on the Diffusion and Osmosis Test. They were grouped under the headings of the particulate and random nature of matter, concentration and tonicity, the influence of life forces on diffusion and osmosis, the process of diffusion and the process of osmosis.

Table 2.1

Percentages of Responses by College Biology Non-Majors and Majors with specific Misconceptions detected by the Diffusion and Osmosis Diagnostic Test

Alternative Conceptions	Non-majors	Majors	Item
The particulate and random nature of matter			
1. Particles move from high to low concentrations because:			
a. They tend to move until the two areas are isotonic and then the particles stop moving.	32.5	33.3	2
b. There are too many particles crowded into one area, therefore they move to an area with more room.	31.7	26.5	2
2. As the difference in concentration increases between two areas, rate of diffusion:			
a. increases because the molecules want to spread out.	27.6	29.1	3
b. decreases because if the concentration is high enough, the particles will spread less and the rate will be slowed.	18.7	12.8	3
3. When a drop of dye is placed in a container of clear water the:			
a dye molecules continue to move around because if dye molecules stopped, they would settle to the bottom of the container.	13.0	6.0	6
b. dye molecules continue to move around because this is a liquid; if it were solid the molecules would stop moving .	6.5	11.1	6
Concentration and tonicity			
1. A glucose solution can be made more concentrated by adding more glucose because the more water there is, the more glucose it will take to saturate the solution.	22.0	20.5	4
2. Side 1 is 10% sale solution and side 2 (15% salt solution).			
a. Side 1 is hypotonic to side 2 because water moves from high to low concentration.	15.4	6.0	9
b. Side 1 is hypertonic to side 2 because the water moves from high to low concentration.	10.6	3.4	9

(Adopted from Odom and Barrow, 1995)

Table 2.1 continued

Alternative Conceptions	Non-majors	Majors	Item
Influence of life forces on diffusion and osmosis			
1. If a plant cell is killed and placed in a salt solution, diffusion and osmosis will not occur because the cell will stop functioning.	26.8	22.2	11
Process of diffusion			
1. The process responsible for a drop of blue dye becoming evenly distributed throughout a container of clear water is:			
a. diffusion because the dye separates into small particles and mixes with water.	18.7	20.5	1
b. osmosis because there is movement of particles between regions of different concentrations.	14.6	5.1	1
2. When sugar is added to water, after a very long period of time the sugar will be more concentrated on the bottom of the container because:			
a. There will be more time for settling.	25.2	7.7	5
b. The sugar is heavier than water and will sink.	22.0	40.2	5
c. Sugar dissolves poorly or not at all in water.	8.9	12.8	5
Process of osmosis			
1. Two columns of water are separated by membrane through which only water can pass. Side 1 contains dye and water; side 2 contains pure water. After 2 hours, the water level in side 1			
a. will be higher because water will move from the hypertonic to hypotonic solution.	22.0	16.2	8
b. will be higher water moves from low to high concentrations.	13.0	15.4	8
c. will be lower because water will move from the hypertonic to hypotonic solution.	14.6	14.5	8
d. will be the same because water will become isotonic.	17.1	13.7	8
2. If a fresh water plant cell were placed in a beaker of 25% salt water solution, the central vacuole would decrease in size because salt absorbs the water from the central vacuole.	35.8	19.7	10

(Adopted from Odom and Barrow, 1995)

Based on the results of the study done by Odom and Barrow(1995), it is obvious that biology majors and non-majors continue to have alternative conceptions of diffusion and osmosis after instruction related to these important concepts. The Diffusion and Osmosis Diagnostic Test appears to provide a feasible approach for evaluating students' understanding and for identifying alternative conceptions of diffusion and osmosis concepts. The identification is of direct relevance for biology teachers because this knowledge can be used to improve instruction.

For the purpose of this study, the Diffusion and Osmosis Diagnostic Test(DODT) was used to detect the common and recurring alternative conceptions held by the form four biology students. However the aim of this study was also to see whether the formal reasoning ability had an affect on the conception and alternative conception of diffusion and osmosis.

2.4 Formal Reasoning Ability and Science Achievement

Understanding the effects of constructivist and inquiry approaches in science education and studying students' abstract reasoning abilities have become very important. In this process, cognitive growth is considered as a highly desirable educational goal, and many curriculum are designed to develop students' particular cognitive skills. The meaning of cognitive development can be defined as students' understanding levels of the concepts or principles, students' operational stages; the concrete operational stages; the concrete operational stage or the formal operational stage, and thinking abilites Bybee and Sund (1990).

Espojo, Good and Westmeyer (1975) and Cohen (1980) expressed the view that one of the important aims of science education was to develop students' formal reasoning or thinking abilities. Lawson, Karplus and Adi (1978) defended the idea that students should reach a formal operation level to understand abstract science concepts and the processes of scientific investigation.

Cepni and Ozsevgec (2002) argued that if assessment questions did not match students' cognitive development levels, they would not contribute to developing students' cognitive reasoning. These types of questions also demolished their self-confidence and their enthusiasm towards science lessons and as a result, they would not progress in the cognitive domain as expected.

Many studies shown that the majority of middle and even secondary school students did not reach formal operation levels (Shayer, Kucherman and Wylam, 1976; Lawson, Karplus and Adi, 1978; Shemesh, Eckstein and Lazarowitz, 1992; Adey and Shayer, 1990, 1994).

Ehindero (1979) investigated the relationship between performance in secondary school biology and the acquisition of concrete and formal operational concepts. Subjects (N=110) aged 13 to 15 in Standards 9 and 10 were randomly selected form six secondary schools on Oyo state, Nigeria. On the basis of their teachers' assessment, the subjects were divided into two groups, higher and lower achievers in biology. Two concrete operational tasks that is conservation of volume and class inclusion and four formal operational tasks that is proportional reasoning, a pendulum, syllogistic reasoning and combinatorial reasoning were used.

The two concrete operational tasks were performed with ease and everyone passed them. For the task on conservation of volume, subjects used identity, reversibility and compensation to explain their responses. The counter-suggestions advanced by the experimenter had no effect on their responses, which Ehindero (1979) interpreted as showing intellectual maturity on the part of the subjects.

When tested on formal operational concepts, the lower achievers were found to be mainly still at the stage of concrete operations, whereas the higher achievers were at the stage of formal operations. It was clear, therefore, that for students to perform well in biology they had to have attained the stage of formal operations. On the other hand, formal operations may be necessary but not the whole cause of achievement in biology.

Piburn (1980) investigated the connection among spatial reasoning that is the ability to perceive spatial patterns or to maintain orientation with respect to objects in space and formal thought, especially the schema of proportionality and science achievement of 6th form that is 11 years high schools students in New Zealand. The subjects were found to be 18% concrete reasoners and 35% formal reasoners and the others were at a transitional level.

Wilson and Wilson (1984) observed formal operational thought for two-year National High School and one year preliminary year program students in Papua New Guinea. The study was designed to investigate 11th grade students' Piagetian levels, determine developments in cognitive level during a two year instructional program and examine the relationship between level of cognitive development and science achievement at a National High School(NHS) and one year preliminary year program(PY).

After the trial, a Pendulum task was used to assess students' cognitive levels. The task was adapted to a group format and responded to by the subjects (N=739 for NHS and N=165 for PY) by using the structured answer sheets. They found that there were significant developments in students' cognitive domain for the NHS program. However, most of the students were at the transitional level. In addition to this, a low correlation between cognitive development and science grade was found.

Johnstone and Mahmoud (1980) discovered that 'osmosis and water potential' were regarded by students and teachers as the most difficult of fifteen major biological concepts. Why should the osmosis topic prove to be so difficult? According to Johnstone and Mahmoud (1980), it required a high level of reasoning as well as an understanding of the relationship between macro- and Microsystems in phenomena such as concentration, membranes, direction of molecular movement. According to Arnold and Simpson(1982) the understanding of the osmosis topic requires formal reasoning.

According to Lawson and Renner (1975), secondary school students who are still reasoning at the concrete level are able to learn very little, if any, of what is taught in an abstract verbal way.

According to Shemesh, Eckstein and Lazarowitz(1992), young adults are still in the process of developing their cognitive abilites. Less than 50% of high school students have mastered formal operational reasoning. The secondary school curriculum in science and mathematics includeed many abstract concepts which required formal operational ability to understand fully.

The relationship between measured formal thought and that required to understand formal concepts in college level physical science was studied by Boram and Renner (1985). Using individual interview tasks, 49 students enrolled in a physics course for elementary teachers were evaluated for their abilities to use: (1) combinatorial, (2) separation and control of variables, (3) proportional reasoning and (4) reciprocal implications.

During one semester, the students were given experiences with 30 physics concepts; six of these concepts dealing with torque, electricity, optics and heat were used in the research. Understanding these concepts required using one or more of the characteristics of formal thought.

According to Boram and Renner(1985), analysis of the data led them to conclude that a non-significant relationship existed between formal thought characteristics required to solve a problem and demonstrating the possession of those characteristics. When success on each of the interview tasks was correlated with success on each of the other interview tasks, all correlations were significant and moderately high, leading to the conclusion that sucsess on a problem which required formal thought depended on an overall formal thought structure.

Mulopo and Fowler (1987) made a study of 120 Zambian high school students' level of intellectual development, their performance in chemistry and their grasp of scientific concepts. Sixty were at the stage of concrete operations and the rest were at the stage of formal operations. The performance of the latter was superior to that of the former.

Champagne, Klopfer and Anderson (1980) exmined factors that wer most significant in predicting students' achievement in classical mechanics. A study was conducted on 110 students, with logical reasoning skills being one of the factors studied. The Logical Reasoning test administered to the students required tem to apply the logical reasoning to verbal and diagrammatic representations of the physical world. Results showed that the mechanical achievement score was correlated significantly with the logical reasoning score of the students.

Lawson and Renner (1975) investigated the relationships of science subject matter and developmental levels of students. In order to determine the levels of cognitive development of the students in biology, chemistry and physics classes, four Piagetian tasks were used.

The findings showed that about 65% of the biology students were operating at the concrete level, 92% of the chemistry students were categorized as transitional thinkers and were operating above the Concrete IIB level and below the Formal IIIB level while approximately 85% of the Physics students were classified as above the concrete IIB level and below Formal IIIB level. Lawson and Renner(1975) reported that only 4.8% of the entire sample of 134 students were considered formal IIIB thinkers.

Lawson (1983) investigated the role of developmental level, disembedding ability, mental capacity, prior knowledge and beliefs in predicting science achievement using a sample of 96 undergraduate students, aged 18.8 years to 38.7 years. The findings from the to Classroom Test for Formal Reasoning showed that 13.7% of the students were at concrete operational level, 57.5% were transitional between concrete and formal levels and only 28.8% were at formal operational level.

Chiappetta (1976) reviewed a number of research studies relating cognitive development of students to science achievement. The findings of many of the research studies indicated that the concrete thinkers functioned only at the concrete operational level and not at the formal operational level in science. The formal thinkers might have the ability to function at formal operational level, but they frequently functioned at the concrete operational level in science. Chiappetta (1976) concluded that the majority of the students functioned at the concrete operational level on their understanding of science subject matter.

From the above reviews of literature relating to formal reasoning ability and science achievement, it could be concluded that research studies in general revealed that students at higher cognitive level tended to attain better performance in science. On other words students with better reasoning ability would have fewev alternative conceptions.

2.5 Gender and Achievement in Science

Gender differences in science have received serious attention in the science education research for the last two decades. Boys and girls have been compared on variables such as achievement, attitude, motivation, interest and performance behaviours (e.g. Eccles & Blumenfield, 1985; Erickson & Erickson, 1984; Greenfield, 1997; Jovanovich & King, 1998; Kahie, Parker, Rennie & Riley, 1993; Morrell & Lederman, 1998; Simpson & Oliver, 1985).

In a comprehensive review of studies about correlations among affect, ability, achievement and gender, Steinkamp and Maehr (1983) reported that (a) in science and cognitive ability, boys did slightly better than girls (b) the achievement-with-affect correlations were similar for boys and girls, and (c) for both boys and girls, the achievement-with-cognitive ability relationship was strongest on biology and physics.

Smail and Kelly (1984) used a series of multiple choice, structured and essay questions to assess a total of 2065 secondary school students from 10 different schools in England. They wanted to find out whether there were gender differences in science knowledge, spatial ability and mechanical reasoning. They discovered that female and male students were approximately equal in science knowledge. However, males did better than females in physical sciences, and on tests involving spatial ability and mechanical reasoning.

Differences in science-related experiences extend outside the classroom. It has been found that girls as a group have much less out-of-school experience than boys with many of the kinds of skills and experiences that can later serve to enhance their interest and success in science, including exploration and assembly and even tinkering with science-related hobbies, exploration toys and so forth (Rennie, 1987).

For example, National Assessment of Educational Progress (NAEP) studies over past 20 years have shown a gender gap favoring boys both for overall science achievement and for achievement at the higher scoring ranks.

It was found the gap was small or absent at the fourth-grade level but grew steadily through secondary school (Jones, Mullis, Raizen, Weiss & Weston, 1992; Mullis, Dossey, Foertsch, Jones & Gentile, 1991).

Postelthwaite and Wiley (1991) in their report of the second International Education Achievement (IEA) study of science achievements in twenty-three countries indicated that achievements in physics had the highest gender differences followed by chemistry and biology.

Reap and Cavallo (1992) made use of the assessment technique known as 'mental modelling' to ascertain whether gender differences could be one of the factors related to students' acquisition of science concepts. They assessed 140 10^{th} grade high school students from New York State and found that there were significant gender differences. Male students scored better than the female students in the understanding of science concepts.

Johnson and Murphy(1984), in their comprehensive review of the performance data accumulated in the APU (Assessment of Performance Unit) science survey conducted in England, Wales and Northern Ireland, reported significantly higher performance for boys in tests dependant on physics knowledge. The boys showed higher mean scores on more than 90% of the questions at each age and for about 50% of all the questions, the performance differences reached statistical significance.

Giam (1992) gained similar results in his investigation of students' understanding of concepts in mechanics. In this matter, the male students performed significantly better than their female counterparts.

Mah (1999) used 39 male students and 50 female students in his study on students' understanding of concepts in circular motion. His findings revealed that the male students performed significantly better than the female students in their understanding of the concepts.

Irr contrast, Lew(1987), found no significant differences between the males and females students in the understanding of science concepts.

2.6 Summary

From the review of related literature, it is observed that there are a number of factors affecting students' performance in their understanding of diffusion and osmosis. These factors include formal reasoning ability and gender.

The TOLT has been used in a number of research studies for determining the level of formal reasoning ability. It has been proven to be a reliable paper-and-pencil test suitable for determining of a large number of subjects. On the other hand the DODT was adopted from Odom and Barrow's (1995) study.

The DODT was initially constructed to assess freshman college biology students' understanding of diffusion and osmosis. However, subsequent studies have indicated the DODT to be appropriate for secondary biology students.

Students' level of formal reasoning ability correlated significantly with students' understanding of the concepts. The formal thinkers demonstrated understanding of both concrete and formal concepts better than the concrete thinkers. However, many research studies have indicated that the majority of the secondary school students have not attained the formal operational stage of cognitive development.

Students often bring to biology classes their own meanings of words and views of the world which are different from those to be taught.

In order to explore students' meanings of words and views of the world, interview method and multiple-choice diagnostic test are recommended. However, multiple-choice diagnostic test which is basically a paper-and-pencil test is preferable in eliciting the opinion of a large number of subjects in a study.