1993

Student misconceptions of osmosis and diffusion

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STUDENT MISCONCEPTIONS OF OSMOSIS AND DIFFUSION

By

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A thesis submitted in partial fulfilment of the requirements for the award of Bachelor of Education with Honours at the Faculty of Education, Edith Cowan University

November, 1993

USE OF THESIS

Abstract

Student misconceptions about two fundamental science concepts, osmosis and diffusion, were elicited using an interview-about-events approach.

A concept map and list of 25 propositional statements were used to define the knowledge regarded as important for a sound understanding of the concepts of osmosis and diffusion. The interview probed students' understandings of the propositions.

Eighteen students from a local metropolitan high school were interviewed. These students were selected from four different science classes. Nine students studied Year 12 Biology and nine studied Year 12 Human Biology. Diffusion and osmosis are integral concepts required for thorough understanding of both subjects.

The interview-about-events procedure elicited student understanding of the sub-microscopic processes operating within the concrete phenomena provided at various stages during the interview. Interview data were recorded on tape and later transcribed. Additional information was provided in the form of brief notes compiled at the time of the interview by the researcher and diagrams constructed by

students to represent the molecular processes they thought were occuring in the phenomena being discussed.

Coding categories for student responses were constructed using data from a pilot study. These categories were used to determine the frequency of different types of response elicited during the study.

The investigation revealed that student misconceptions were most often based on poor understanding of the random and continuous nature of particle behaviour. A common student misconception described particles as failing to move independently of the body of matter in which they are contained. Many students believed that particles moved in a specific direction only if made to do so by some external force or if required to do so to establish an equilibrium concentration of solute particles.

This thesis also describes implications for teaching and research, and limitations of the study.

I certify that this thesis does not incorporate, without acknowledgement, any material submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

Erica Joy McKnight

ACKNOWLEDGEMENTS

The author wishes to offer a sincere and heartfelt thanks to Dr Mark Hackling, principal supervisor, for his continued patience, encouragement and support.

Appreciation must also be extended to the students of Forrestfield Senior High School who volunteered their time during this study, to my family for their unfailing encouragement and to the science education lecturers at Edith Cowan University who assisted with the validation of materials used in this study.

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CHAPTER 1

Introduction

Background

Largely due to the popularity of constructivist learning theory and groundbreaking Piagetian research of the 1930's, the study of children's concept development has been the subject of increasing interest in the academic community. In more recent years, research efforts have focussed upon describing student misconceptions and the planning of instruction to bring about conceptual change (Osborne & Freyberg, 1985).

The constructivist tradition and its relevance to concept learning are of particular significance to science education. Learning in science tends towards progressive changes in understanding. Concepts tend to be built upon established frameworks of knowledge. Misconceptions pose a particular problem for the science educator as they create flaws in the framework for future learning, in addition to the more immediate problem of incomplete understanding. In the pursuit of effective education, the teacher needs to identify the alternative frameworks presented by students in order to design instruction that will provide learning experiences that will accomodate students' alternative frameworks and foster sound understanding.

Problem Statement

Misconceptions are commonly defined as a concept or idea that is inconsistent with the acceptable scientific conceptions (Fisher & Lipson, 1982). Misconceptions are extremely common in science (Lavoie, 1989) partly due to the abstract nature of the concepts to be learned (Simpson & Marek, 1988) in combination with the concrete reasoning ability of most secondary school students (Garnett, Tobin & Swingler, 1985; Sheperd & Renner, 1982; Simpson & Marek, 1988).

Biology contains many abstract and often poorly defined concepts (Fisher & Lipson, 1982; Lavoie, 1989). To complicate this, there is a paucity of research into student misunderstandings of biology concepts (Marek, 1986). In this field, the abstract concepts of osmosis (Friedler, Amir & Tamir, 1985) and diffusion (Marek, 1986; Simpson & Marek, 1988; Westbrook & Marek, 1991) have been identified as being fraught with misconceptions.

Misconceptions in science can form a particularly resilient barrier to effective learning. The misconceptions children bring with them to the classroom are tenacious, long standing and resistant to extinction (Gilbert, Watts & Osborne, 1985). To compound this difficulty, student misconceptions are often unrecognised by the teacher and are influenced in unforeseen ways by teaching (Osborne & Wittrock, 1985).

According to constructivist tradition and the generative learning model, learning involves the generation of links between new information and existing schemata. New information is interpreted according to what has been previously learned, building upon an existing framework of ideas (Osborne & Wittrock, 1985). Children's conceptions will not change unless an explanation that appears better to them is presented (Osborne & Cosgrove, 1983). The implication for the teacher then, is to understand the form and basis of student's misconceptions in order to introduce more acceptable cognitive structures.

Rationale

Diffusion and osmosis are foundation concepts integral to sound understanding of many others (Friedler et al., 1985; Marek, 1986; Simpson & Marek, 1985). Diffusion is closely related to understanding of the particulate nature of matter (Comber, 1983; Doran, 1972; Novick & Nussbaum, 1981), solubility (Lavoie, 1989), changes of state and kinetic theory (Osborne & Cosgrove, 1983; Sheperd & Renner, 1982).

Osmosis, a specific form of diffusion, is a particularly important process for many other related science concepts, particularly, water balance in animals, water uptake by plants and internal transport systems (Friedler et al., 1985).

The Western Australian Ministry of Education acknowledges the importance of diffusion and osmosis as major concepts in school science, through their inclusion in the learning objectives of both upper and lower secondary science syllabi (Secondary Education Authority, 1991). The more fundamental biological concept of diffusion is viewed as an important component of instruction in the lower secondary science units Plants and Animals, Matter, Me and My Environment, Water, Ecology, and Biological Field Studies. Diffusion and osmosis are integral to the Year 11 and 12 Biology syllabi and the Year 11 and 12 Human Biology syllabi. These concepts relate specifically to cell transport, cell membrane function, internal transport systems, digestion, contractile vacuole function, excretion and water balance, gas exchange and cell responses to various water solutions (Secondary Education Authority, 1991).

Science teachers must teach students about diffusion and osmosis to the best of their ability, to satisfy the learning objectives mentioned. Since concept learning is dependent upon the generation of links between new and existing information (Osborne & Wittrock, 1985), the teacher must ascertain the structure of existing schema in order to link in new information. To do this, students' conceptual frameworks must be identified. Ultimately the teacher is responsible for the identification of student misconceptions about diffusion and osmosis so that

appropriate instructional strategies can be designed for their remediation.

Purpose and Research Questions

The purpose of this study is to identify and describe students' misconceptions about diffusion and osmosis. More specifically, the project addresses the following research questions:

1. What are Year 12 Biological Science students expected to understand about the concepts of diffusion and osmosis?

2. What misconceptions of osmosis and diffusion can be identified in a sample of Year 12 Biology and Human Biology students?

CHAPTER 2

Literature Review

The purpose of this chapter is to review literature which has relevance to the development of conceptual frameworks involving osmosis and diffusion and the identification of related misconceptions. Theoretical frameworks relating to concept development are discussed and related learning models considerered. The review then sheds light upon student understandings and misunderstandings of biology concepts, the origin of misconceptions and specific misconceptions elicited through previous research in this field. Methodological issues are then discussed, concentrating upon ways of probing student concepts and issues of reliability, validity and ethics.

Theoretical Frameworks

Research paradigms are the bodies of knowledge, methodologies and perspectives that govern study in a specific field. The constructivist paradigm provides a foundation for much of the theory regarding children's conceptions. Osborne and Wittrock (1985) describe three additional traditions in educational psychology which have had significant influence on science instruction in recent decades. These are the developmental, generative learning and information processing paradigms.

Piaget is largely responsible for research concerning child development within the realms of the developmental

paradigm. Piaget describes four sequential, age related stages of cognitive development; sensori-motor, pre-operational, concrete operational and formal operational. High school involves a transition from concrete to formal operational status for many students. The attainment of formal operational status involves the development of ability to conceptualise abstract themes. Concrete operational status is limited to understanding concepts which are readily perceived by the senses, "hands on" logic.

It is also suggested that Piaget was a constructivist (Osborne & Wittrock, 1985). Evidence for this statement is cited in two parts. First, Piaget considered that all knowledge was constructed by the individual through interaction with the world and a drive to make sense of it. Second, knowledge is proposed as an individual's representation and interpretation of constructed meanings. Piagetian research has had a significant influence on the evolution of the constructivist paradigm.

Ausubelian research has also had a significant influence on constructivist theory and the understanding of concept attainment. Ausubel (1968) considered cognitive development to be a reorganisation of mental constructs resulting from interaction with the environment (Gilbert & Watts, 1983). Ausubel also considers prior learning to be paramount in the understanding, interpretation and processing of new information.

> "The most important single factor influencing learning is what the pupil already knows. Ascertain this and teach him accordingly." (Ausubel, 1968, p vi).

Kelly (1963) refined further understanding of conceptual development. Kelly proposed that concept development was an active process involving an individual continuously generating his or her own conceptions of stimuli. Personal Construct Theory (Kelly, 1963) uses the metaphor "man-the-scientist" to describe the view that the generation of varied conceptions for phenomena is an essential and unavoidable aspect of an individual's desire to make sense of the world around them. Misconceptions, in Kelly's view, are an inevitable component of cognitive development.

The Generative Learning Model (Osborne & Wittrock, 1983, 1985) is an easily applied model representing children's concept development that lies within the constructivist paradigm. This model, represented by Figure 1, illustrates the way in which information is attended to, processed, transferred and stored within the component parts of the human memory system.

According to the Model, sensed experiences are processed according to the level of interest and relevance accorded to them by the learner. Sensory input that has been actively attended to then passes to the short term memory where the meaning of the new information is

constructed. New meanings are constructed according to existing knowledge networks stored in long term memory.

The fundamental premise of the Generative Learning Model is that perceptions and meanings are constructed in ways that are consistent with prior learning. Prior learning influences the selection of sensory input, attention, links generated between new and existing information, construction of meaning and the evaluation of ideas (Osborne & Wittrock, 1983).

Generative learning and the active construction of meaning require the learner to integrate new understandings into existing knowledge networks. Misconceptions arise when prior learning influences the active construction of meaning so that new understanding is not consistent with scientific views. Actively constructed unscientific understandings are linked strongly to the understanding of other related concepts, making these misconceptions both difficult to change and responsible for the unscientific interpretations and representations of new information.

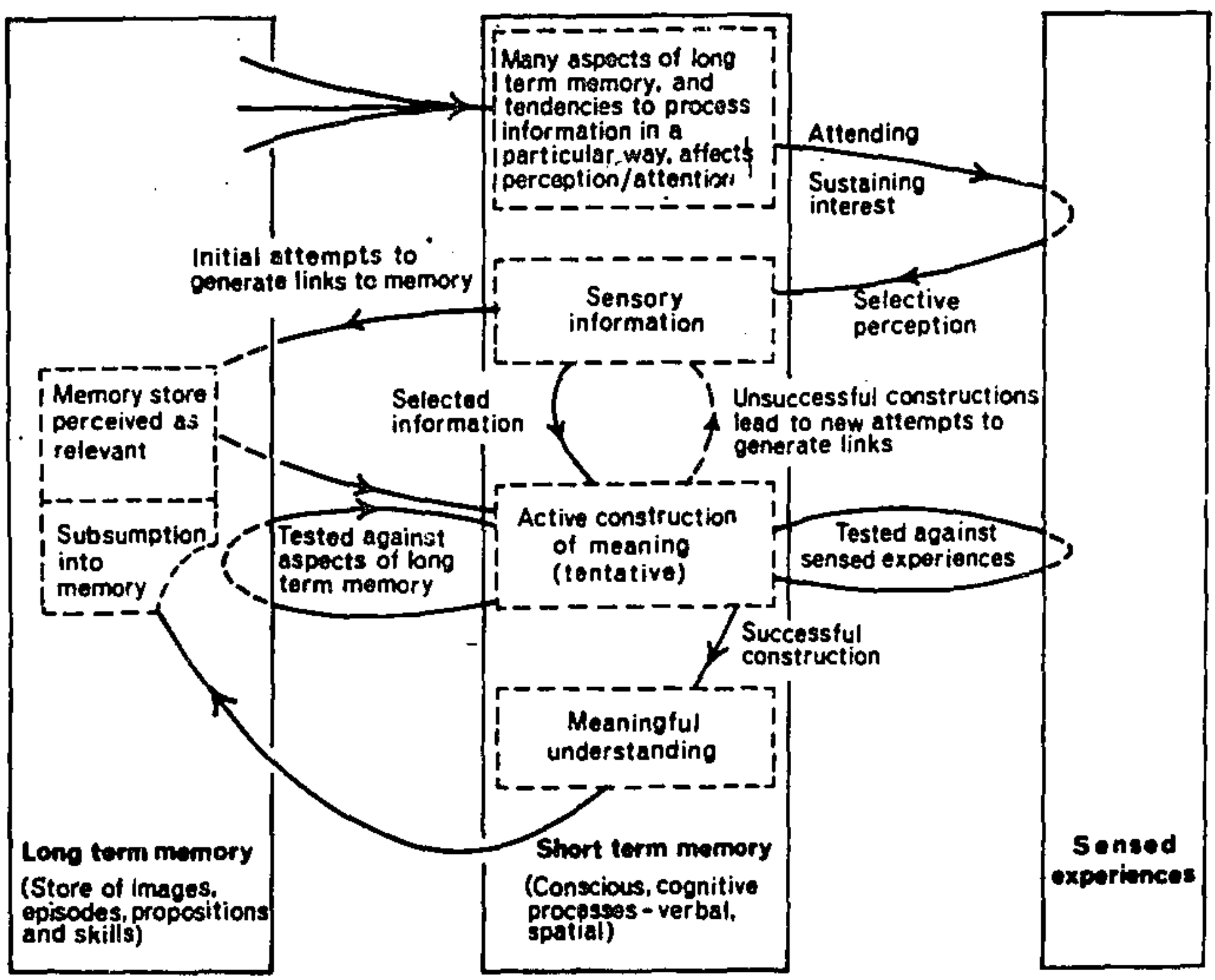


Figure 1. Schematic representation of the Generative Learning Model (Osborne & Wittrock, 1983).

A constructivist orientation has become increasingly popular in the understanding of children's concept development (Driver, 1982; Osborne & Wittrock, 1985). The constructivist paradigm considers an individual's prior learning to be fundamental to subsequent processing of information into representations and interpretations that make sense to the individual. A number of researchers highlight the importance of children's prior learning to their development and understanding of science concepts (Driver, 1981; Gilbert, Osborne & Fensham, 1982; Lavoie, 1989; Osborne, 1980; Treagust, 1988).

The information processing paradigm proposes a complementary model for concept development. This model elaborates on the importance of processing, retrieval and storage of information within the memory systems. The information processing psychology paradigm proposes that concepts are stored as semantic networks within long term memory. Storage involves a central node of information being connected to other nodes via linkages (Stewart & Atkin, 1982).

The information processing model is attractive in its simplistic representation of the flow of information between the sensory information store, short term memory and long term memory. As such, the Model supports the theory of generative learning in that it proposes a way in which concepts can be integrated into related semantic networks in the process of generating understanding.

The Origins of Misconceptions

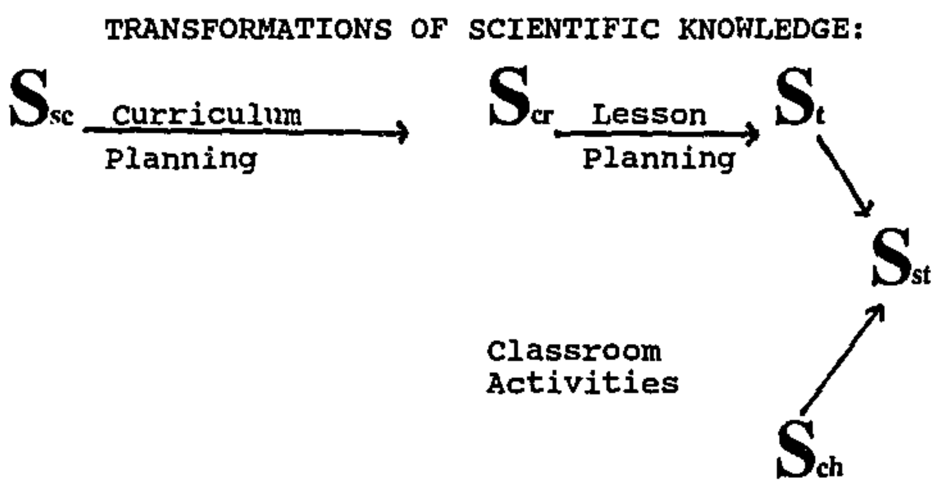
Children's concepts can be viewed as knowledge structures or networks that have been constructed in order to provide, from the child's point of view, a sensible and coherent understanding of events in the world around them (Osborne & Gilbert, 1980a).

Children's concepts seem logical to the child. They are component parts of larger knowledge networks and are also highly resistant to change (Gilbert et al., 1982; Osborne & Wittrock, 1983).

Misconceptions arise when the child's understanding of phenomena is not consistent with the accepted scientific conception (Lavoie, 1989). Misconceptions have also been termed alternative frameworks (Ausubel, 1968), conceptual primitives (Fisher & Lipson, 1982), children's science (Gilbert et al., 1982) and preconceptions (Novak, 1977). In addition, Lavoie (1989) cites child artificialism, children's scientific institutions, alternative conceptions, mini theories and naive theories as synonyms quoted in recent literature.

Gilbert et al. (1982) describe concept learning in science as the interaction between five different types of scientific understanding. These classes of understanding are the scientist's view of science, curricular science, teacher's science, children's science and student's

science. Student's science is seen as the desirable product of the interaction between teacher's science and children's science views. Effective teaching aims to match student's science as closely as possible to the scientist's science views. This interaction is illustrated in Figure 2.



Curricular science S_{cr} Children's science S_{ch}

Scientist's science S_{sc} Student's science S_{st}

Teacher's science S_{t}

Figure 2. The development of student's science (Gilbert et al., 1982).

Science instruction is often unsuccessful in producing the required scientific understandings (Osborne & Wittrock, 1985). The ideas and alternative frameworks that students bring with them to class are affected by science teaching

in unanticipated ways (Driver & Easley, 1978; Fisher & Lipson, 1982; Osborne & Wittrock, 1985).

Science instruction produces different kinds of outcomes in terms of student understanding. The actual outcomes of science teaching contrast with those commonly anticipated by teachers, many of whom believe that their science views will be interpreted in the desired ways and replace those already held by the students (Gilbert et al., 1982).

Gilbert et al. (1982) describe five ways in which teaching outcomes typically eventuate. Students' ideas about science may remain unchanged by instruction. Alternatively, misconceptions may be reinforced. Students may evolve two different perspectives regarding an idea, or the child's ideas and the teacher's perspectives may mix in a heterogeneous fashion, creating a disjointed and incoherent understanding. Ideally a unified outcome of coherent understanding can be achieved.

Osborne and Wittrock (1985) identify a number of possible explanations for the frequent development of misconceptions in science. These explanations include student perceptions that their current conceptual framework is plausible and failure to test current ideas against other constructions for adequacy. It is also suggested that potential threat to one's emotional security is avoided through resistance to major restructuring of ideas.

It is easier for the child to link new information to existing ideas rather than to reorganise an entire semantic network to provide more appropriate links or background. No correlation has been demonstrated between the development of misconceptions in science and either intelligence or reading ability (Doran, 1972).

Previous Studies

Misconceptions in science are extremely common (Fisher & Lipson, 1982; Lavoie, 1989; Simpson & Marek, 1988). Although biology is fraught with misconceptions, research has focussed most specifically on the physical sciences (Marek, 1986). There is a paucity of research devoted to identification of student misconceptions of diffusion and osmosis in upper secondary biological sciences

Research has shown that students hold similar types of misconceptions across a range of science concepts. Gilbert, Watts and Osborne (1985) delineate five categories of misconception. These are; an everyday language use of scientific terms, applying self-centred or human centred viewpoints to objects, the belief that things that cannot be seen do not exist, endowing objects with human characteristics and endowing objects or forces with unwarranted physical quantities. Similar categories have been replicated in the research of Doran (1972); Friedler et al. (1985), Osborne and Cosgrove (1983) and Osborne and Gilbert (1980b).

Of particular relevance to sound concept development about osmosis and diffusion is a thorough understanding of the particulate nature of matter. Research into student misconceptions about particle theory has elicited frequent, fundamental misunderstandings about the motion and spacing of particles and the intermolecular forces between them (Comber, 1983; Doran, 1972; Novick & Nussbaum, 1981; Simpson & Marek, 1988; Westbrook & Marek, 1991).

Misconceptions about the particulate nature of matter are reflected by similar misunderstandings regarding cell theory and cell water relations. Students' poor comprehension of kinetic theory and particle movement is frequently responsible for misconceptions about random motion, water transport through the cell and related osmotic processes (Friedler et al., 1985).

The types of misconceptions found in studies of the particulate nature of matter are consistent with the five categories delineated by Gilbert et al. (1985). The random movement of particles is frequently attributed to anthropomorphic or anthropocentric reasons. Particle motion is seen by children to be due to a will or a purpose, to "make things fair between the two sides of a membrane", for example. Particles may also be perceived as "seeing that the balance of particles is unfair". The scientific terms used in the classroom also contribute to the formation of misconceptions. The terms "osmotic pressure", "osmotic potential", "solubility" and "water

potential" are poorly understood (Friedler et al., 1985).

Methodological Issues

There are four main methods of probing students' views; clinical interviews, word association or word sorting tasks, writing definitions and rating ideas on bipolar dimensions (Sutton, 1980). In addition, Treagust (1988) advocates the use of diagnostic testing with multiple choice instruments while Simpson and Marek (1988) and Westbrook and Marek (1991) use concept evaluation statements. Other research has been successful in using a combination of these techniques (Friedler et al., 1985; Novick & Nussbaum, 1981).

The clinical interview has been a popular method of identifying concept understanding since its use by Piaget in the 1930's. The clinical interview involves individual students discussing their science views with an interviewer on a one-to-one basis. The flexible and sensitive nature of this method has inherent advantages over the use of formalised "pencil and paper" methods. The interviewer has the opportunity to focus upon student statements that indicate any discrepancy or misunderstanding. Misunderstandings about the requirements of the interview, questions or procedure can be clarified, difficulties with reading and writing ability are avoided and the method is non-threatening to the student as it is completely nonjudgemental (Gilbert & Osborne, 1980).

The clinical interview method has been modified in recent years to improve the elicitation of science understandings. The interview-about-instances (IAI) method (Gilbert & Osborne, 1980; Gilbert et al., 1985; Osborne & Gilbert, 1980) and the interview-about-events (IAE) method (Osborne & Cosgrove, 1983) are such modifications. The underlying assumption behind the IAI approach is that the student's ability to differentiate between instances and non-instances of a concept is a key measure of concept understanding. Both techniques use stimulus material to help elicit students' thoughts about a concept. The IAI approach uses diagrams of instances and non-instances, the IAE approach uses real, everyday examples of the phenomenon of interest. Students are encouraged to verbalise the reasons and thought processes behind the statements they make.

Successful interviews require experience and training on the part of the interviewer and a limited but adequate choice of stimuli for the IAI method. The interviews themselves may be difficult to organise and very time consuming (Gilbert & Osborne, 1980).

Gilbert et al. (1985), recommend the use of pilot studies to refine interview schedules. Revision of the instrument provides the opportunity to remove any anomalies in design, wording or sequencing.

Simpson and Marek (1988) and Westbrook and Marek (1991) use concept evaluation statements to probe student understandings. Concept evaluation statements are written descriptions of the defining attributes of a concept that do not have the concept named in the statement. Students are required to identify and explain the concept that is described. This method of probing students' understanding appears limited by the students' individual abilities with written language. In addition, evaluation statements tend not to elicit the students' own idiosyncratic meanings about the concept. Hence, this method may be best suited as a supplement to more comprehensive techniques, such as interviews.

The use of diagnostic tests designed in a two-tier multiple choice format is useful in the identification of student misconceptions (Treagust, 1988.) Common misconceptions about a concept are identified using interview studies and then used as distractors in the first tier of multiple choice questions. The second tier of questions require students to select a reason for their choice of answer to the first section. Students may indicate that they hold a common misconception about the concept being investigated through a choice of distractor in the first tier. An insight into the reason for the choice of a distractor is elicited by student decisions in the second tier of the test question.

Interviews are used initially to identify common misconceptions then multiple choice tests are applied to larger sample groups to establish the generalisability of interview findings. Triangulation using both quantitative and qualitative data gathering methods is recommended to enhance reliability (Jick, 1979).

CHAPTER 3

Methodology

Defining the Knowledge of Osmosis and Diffusion Expected of Year 12 Biology and Human Biology Students

The objectives of the Year 11 and 12 Biology and Human Biology syllabi (Secondary Education Authority, 1991) were analysed to determine what understanding of diffusion and osmosis was expected from students at the completion of their courses. According to the syllabi, students were expected to be able to apply an understanding of osmosis and diffusion in the contexts of gas exchange, cell-water relationships, absorption of nutrients, excretion of metabolic wastes and other life processes.

A concept map, based on the objectives of the biology and human biology syllabi, was constructed by the researcher. This concept map (Appendix 3) shows the various concepts and the conceptual relationships required for a sound understanding of osmosis and diffusion.

A set of propositions defining the knowledge of diffusion and osmosis required by students of Biology and Human Biology was prepared based upon the concept map. These propositions (Appendix 4) were appraised and validated by two science educators from a Western Australian university. The interview schedule was developed to probe students' understandings of these propositions.

Selection of Data Gathering Technique

The purpose of this study was to identify and describe students' misconceptions about diffusion and osmosis.

An interview - about - events (IAE) approach, as described by Osborne and Cosgrove (1983) was selected as the most appropriate and potentially effective means of probing student understanding of these science concepts. The IAE technique is an interview method which utilises concrete examples of the phenomenon of interest to stimulate discussion about the concept.

The IAE technique provides flexibility to clarify and investigate perceived misunderstandings while avoiding the rigidity and language difficulties inherant in pencil and paper forms. The use of concrete examples of the phenomenon allows the interview matter to appear more realistic and hence more easily approachable by the interviewee.

Instrument Development

The absence of any previously developed, tested instrument to investigate student understanding of diffusion and osmosis meant that it was necessary to construct a schedule for that purpose. The propositions defining the knowledge required for a sound understanding of osmosis and diffusion were used to identify eight concept areas for investigation. A series of four events

were selected to represent and provide a basis for discussion about the concept areas (Figure 3).

Event	Concept areas investigated
1. Glass of water	Particle theory Kinetic theory of matter Evaporation Diffusion
2. Sugar cube in a glass of water	Particle theory Kinetic theory Dissolving Concentration difference Diffusion
3. Dry sultanas and sultanas soaked in water	Kinetic theory Concentration difference Cell theory Diffusion Osmosis
4. Red blood cells in water, plasma and salt solution	Kinetic theory Concentration difference Cell theory Diffusion Osmosis

Figure 3. Events Used to Probe Understanding of Selected Concept Areas

Particle theory proposes that matter is composed of submicroscopic particles called atoms and molecules. The kinetic theory of matter proposes that particles vibrate continually and in random directions. The speed of motion of the particles is affected by changes in temperature and hence kinetic energy.

Evaporation involves the change of a body of matter from liquid to gas, where particles possess enough kinetic energy to change phase. An understanding of dissolving

involves knowledge of solid particles moving randomly into and through a liquid to form a solution.

The concept area of concentration difference involves an understanding that the concentration of particles in one area will be higher than in another area. Particles will vibrate randomly to cause nett movement across the concentration gradient until the concentration is even throughout. The concepts of diffusion and osmosis require an understanding of the other concept areas. These processes involve the movement of particles in gases or solutions by random motion across concentration gradients.

Cell theory requires students to apply an understanding of the processes of osmosis and diffusion to the movement of water and solutes into and out of living cells.

The sequencing of the presentation of events was designed so that general concepts, such as particle theory and kinetic theory, were investigated before the more specific concepts of diffusion and osmosis. This aspect of design was incorporated to allow the researcher to identify the apparent basis of misconceptions in the specific concepts of diffusion and osmosis.

Events 1, 2 and 3 were illustrated using actual examples of a glass of water, sugar cube, dry sultanas and sultanas distended through soaking in water. In Event 4,

students were presented with a drawing of a red blood cell as it appears in blood plasma. Students were asked to draw how a blood cell would appear after being in pure water and a salt solution for some time. Students were also required to describe their understanding of diffusion and osmosis and any similarities or differences they perceived to exist between the two processes.

The IAE interview schedule was administered to two students in a pilot study. The results of the pilot interviews indicated that it was not necesary to modify the events, but some redundant questions were deleted from the schedule. The pilot study also provided the researcher with experience in the interview methodology.

Adhering to the syllabus objectives helped ensure the instrument was valid in terms of testing the knowledge expected of Year 12 Biology and Human Biology students. The concept map was based on the objectives. The concept map provided the framework for the propositions. These, in turn, were validated by science educators. The propositions were then used to develop the interview schedule. A copy of the interview schedule is presented in Appendix 1.

Subjects

Eighteen Year 12 Biology and Human Biology students were selected from a Perth metropolitan senior high school. Nine students were selected from each of Biology and Human

Biology. The students were selected from four different classes. Each class had a different teacher.

A stratifed sampling technique was used to select interviewees from the two subject areas of Biology and Human Biology. Students were chosen from grade related strata. Each subject area supplied two A grade, three B grade and four C grade students. Approximately equal numbers of male and female subjects were selected.

Teacher assistance was sought in the process of selection to help identify students from each strata who were self-confident and good communicators. It was intended that students with these qualities would be more likely to talk freely during an interview.

Participation in the study was voluntary. Students were required to read and sign a consent form prior to the interview taking place.

Procedure

Interviews were conducted on school grounds in an upper school laboratory area. This area was isolated from much extraneous noise while being familiar to students.

Students were introduced to the researcher when first requested to participate in the study. At that time, interviewees were informed of the general purpose of the study "To find out what sort of problems Year 12s have

with some Biology and Human Biology concepts so we can design ways to teach them better."

It was explained to students that participation was voluntary and results were confidential. Attention was given to stress the non-judgemental nature of the interview, that students were not being tested.

Students were not informed of the specific concepts being probed prior to the interview to avoid the possibility of students completing extra research into the concepts. Additional preparation for the interview, above normal study requirements, risked reducing the generalisability of interview results.

Reliability of results was improved through the structuring of each interview in a similar fashion. The researcher developed some rapport with students through casual conversation and informal introductions prior to each interview. Students were reminded of the non-judgemental nature of the interview and that it was "their views" that the researcher was interested in. A pencil, pens, eraser and recording sheet (Appendix 1) were provided for each student. It was explained that students would be asked to discuss and sometimes draw what they felt was occuring in the events they were shown.

The presence of the audio-tape recorder was acknowledged and students were asked if "they minded if the

tape recorder was on as it is difficult for me to both pay attention to what you are saying and write it all down at the same time".

Questioning began with the introduction of the first event and delivery of the first key question from the interview schedule (Appendix 1). Follow-up questions were dependent upon the nature of the response to the key questions. In this semi-structured format all students were asked the same key questions and yet it was possible to choose follow-up questions to probe for possible idiosyncratic responses while maintaining interview reliability.

Data Analysis

Data from the interviews were in the form of audio recordings and completed record sheets. The record sheets supplemented interview data, clarifying the meaning of statements made by students during the interviews.

The audio recordings were coded according to the level of understanding demonstrated for each of the knowledge propositions. For each proposition, student understanding was coded as either sound understanding, incomplete understanding or misconception.

Sound understanding was defined as an explanation of the phenomenon which was scientifically correct and described the molecular basis of the processes occuring.

Incomplete understanding was defined as an explanation which showed that the student was unsure about the processes occuring or offered only partial scientific reason for the phenomenon being discussed. When the student offered an explanation that was not scientifically correct, it was coded as a misconception.

The categories of misconception were described and the frequency of responses in each category were calculated and recorded. The results of this data analysis are presented in Chapter 4.

CHAPTER 4

Results

Introduction

This chapter presents data regarding students' understandings of the 25 propositions and describes in some detail the nature of students' misconceptions.

Student Understanding of the Propositions

Data from the interviews were recorded in terms of student understanding about each of the propositions. Student understanding of each of the propositions was categorised as sound scientific understanding, incomplete understanding or as a misconception. Operational definitions of these categories were provided in Chapter 3. Table 1 lists each proposition and the frequency of student responses in each of the three categories.

TABLE 1

Percentage of Student Responses (n = 18) Indicating Sound Understanding, Incomplete Understanding or Misconceptions of the Propositions.

Proposition	Sound Und.	Incomp. Und.	Miscon.
1. Matter is composed of particles.	83	17	0
2. Particles are in continuous motion.	44	28	28
3. The motion of particles is in random directions.	22	17	61
4. Heating particles causes them to move more rapidly.	17	67	17
5. Solvents are liquids that dissolve other particles.	78	22	0
6. Solute particles dissolve in a solvent.	78	22	0
7. Solute and solvent together make a solution.	100	0	0
8. Water is the solvent in living things.	56	44	0
9. Common solutes in living things are ions, oxygen, glucose and carbon dioxide.	17	83	0
10. The amount of solute dissolved in solvent is the concentration.	100	0	0
11. Random motion moves solute particles through the solvent.	0	33	67
12. Diffusion occurs when random motion causes nett movement from an area of high to an area of low concentration.	22	50	28

13.Diffusion is slow and only effective across short distances.	0	100	0
14.Rates of diffusion can alter with changes in concentration, particle size, membrane thickness, temperature and surface area.	0	89	11
15.Rate of diffusion slows as concentration difference gets smaller.	0	100	0
16.Random motion eventually creates even particle distribution in solution.	0	44	56
17.Cell membranes are semi-permeable.	50	50	0
18.Semi-permeable membranes allow some substances through but not others.	61	28	11
19.Cell membranes allow water and small solutes to pass through.	17	55	28
20.Particle size relates inversely to the speed of particle motion.	22	56	22
21.Osmosis is diffusion of water from a high to low concentration through a semi-permeable membrane.	22	50	28
22.Outward nett water movement occurs from cells in solutions containing higher concentrations of solutes.	11	44	45
23 Inward nett water movement occurs in cells in solutions containing lower concentrations of solutes.	50	22	28

24. Large nett water intake can cause an animal cell to burst.	39	33	28
25. Nett water loss causes the membrane to shrink inwards.	22	67	11

Frequent Misconceptions

If greater than 25% of students were found to have misconceptions of a particular proposition, further data are presented regarding those misconceptions. A description of the propositions, the most significant categories of misconception, the frequency of student misconceptions in each category and quotations representative of the student misconception about the proposition are presented. The frequency of students holding misconceptions about the particular proposition is presented as a percentage figure in brackets immediately following the wording of the proposition.

The categories of misconception which have been described include those most frequent and those most relevant to sound understanding of the proposition involved.

The quotations below show the interviewer's speech preceeded by the letter I and the student response preceeded by the letter S. Pauses are denoted by a short series of dots. Beneath each quotation is a code which shows the number given to the student interviewed and a

letter has been used to denote the gender of the individual.

Proposition 2: Particles are continually in motion.

Of the 18 students interviewed, five students (28%) demonstrated misconceptions regarding particle motion. Two categories of response were elicited.

Misconception 2(a): Particles of water move only if the entire body of water is caused to move, particles do not move independently (22%).

I: Can you explain for me what you think any one of those particles might be doing?

S: Just sitting there.....I dunno.

I: If we talk about an individual particle, is it moving or is it stationary?

S: Moving.....I think. It depends if you move the glass. 6F

Proposition 3: The movement of particles in gases and liquids is in random directions.

A total of 11 students (61%) held misconceptions of this proposition. Three important categories of misconception were revealed. Two student misconceptions could not be categorised with any others.

<u>Misconception 3(a)</u>: The direction of particle movement is dependent on the direction of movement of the entire body of matter (28%).

S: Yeh. I think they'd move through the water.

I: And when would they move?

S: Umm... I guess when the water's being moved,...probably all the time. But more when the water's being moved.

16F

<u>Misconception 3(b)</u>: The particles move so that they will create an equilibrium concentration through the liquid (17%).

S: Diffusion.

I: Why does that happen?

S: 'Cos um...there might be too many particles in one area and it has to move to another area 'cos there's not enough particles in the other area.

2F

<u>Misconception 3(c)</u>: The particles move in particular directions because they are alive (11%).

I: How does the sugar move through the water?

S: I think it's the oxygen in the water that causes it to breathe and sort of move.

12F

Proposition 11: The random motion of solute particles enables them to move through the liquid.

Twelve students (67%) demonstrated that they held misconceptions of this proposition. Several students gave responses that fell into more than one category. Seven different categories of response were elicited.

Misconception 11(a): The solute will only move when the solvent moves, the solute molecules are not capable of independent movement (39%).

I: So would the sugar molecule be moving?

S: Yeh, it would be pushed around by the water molecule...be hit by the water molecules.... I don't think it would move on its own.

8M

Misconception 11(b): The solute particles move towards areas of lower concentration in order to achieve equilibrium (28%).

I: Why does the sugar move?

S: The solution wants to form an equilibrium and it can't do that while its got a solid sugar cube. So as the sugar dissolves all the sugar molecules move throughout to form an equilibrium.

14M

<u>Misconception 11(c)</u>: The solute molecules will move to the top of the glass (17%).

I: Why do they rise to the top?

S: Something's pulling them up I s'pose....they wouldn't go down because there's nothing to go down to.

1F

<u>Proposition 12: Diffusion occurs when particles move in all directions by random motion. The nett movement of particles is from a region of high concentration to a region of low concentration, across an area of concentration difference.</u>

Of the 18 students who were asked to define the process of diffusion, five students (28%) demonstrated misconceptions. Five types of misconception were elicited.

<u>Misconception 12(a)</u>: Diffusion is a process which occurs when substances pass through a membrane (22%).

S: Umm... its the moving of a substance through a membrane.

I: Through a membrane?

S: Yeh.

I: What sort of substance?

S: Any molecule.

5M

<u>Misconception 12(b)</u>: Diffusion is a one way process, particles can only diffuse in one direction (6%).

S: It would move out of a object or something... through a membrane by how much... by what the pressure is on the outside and the inside. So if it's umm low pressure on the other side it would move into the other area.

I: Can you think of any ways those two terms are the same and any ways that they are different?

S: Osmosis would probably be the whole lot... water moving... leaving and staying. Diffusion is just when it crosses it once and it crosses to the other side.
15F

<u>Proposition 16: Movement of solute particles through a solution due to random motion in all directions will eventually cause nett particle movement to be zero and the distribution of the solute to be even through the solution.</u>

Ten of the students (56%) demonstrated misconceptions about this proposition. Four categories of misconception were elicited, some responses demonstrated misconceptions representative of more than one category.

<u>Misconception 16(a)</u>: Solute particles move specifically towards areas where there is more room available (28%).

S: Because like... the sultana here... its like a certain

amount of water goes in and no more can go in 'cos the thing's full up. The sugar particles start coming out.

I: Why do they do that?

S: 'Cos there's no more room in there.

7F

<u>Misconception 16(b)</u>: Solute particles do not move independently and will only move if made to do so by some other force (28%).

S: If it's really really concentrated then all the umm and it can't dissolve any more sugar... then there's gonna be no more water molecules to attach the sugar ... the sugar won't move 'cos there's no more attractions.

<u>Misconception 16(c)</u>: Solute particles can only move into cells if they are needed by the cells (22%).

I: How would that affect it being able to get through?

S: It would only let some things through it and it wouldn't let some things made up of the wrong thing umm might have the wrong make or the wrong size so it mightn't umm be able to get through it. It might be just like made up of something that's not what the cell needs....I think if its something that the cell didn't need.. it wouldn't get in in the first place.

10F

Proposition 19: Cell membranes will generally allow water and small solutes to pass through them.

A total of six students (28%) held misconceptions of this proposal. All six students held the same type of misconception.

Misconception 19(a): Membranes will let any type of particle into the cell so long as it is needed by that cell (28%).

I: Why is the membrane like that?

S: To allow the molecules or whatever to pass in and out.

I: What can get in and out?

S: Things that they need.... things that go in are things that are needed by the body, like oxygen. Things that go out are wastes like carbon dioxide.
6F

Proposition 21: The diffusion of water particles across a semi-permeable membrane from a region of high concentration of water to a region of low concentration of water is known as osmosis.

Five students (28%) held discernible misconceptions regarding explanations of the process of osmosis. However, a further 50% of students demonstrated particular problems in applying an understanding of this process to the events they were shown. Four categories of misconception were elicited.

Misconception 21(a): Water particles move in one direction only (22%).

I: And why wouldn't they move the other way?

S: Well because they only... the pressures only forcing them to go one way then so when they go inside the sultana they can go the other way.
15F

Misconception 21(b): Water moves in order to establish an equilibrium concentration throughout the liquid (17%).

I: How has the water got into the sultanas?

S: Water moves from a high concentration to a low concentration.

I: Why does it do that?

S: There has to be a balance.... and to make it balance the water moves from the high to the low pressure areas to make a balance between them.
13F

Misconception 21(c): Water particles move in directions that allow them to occupy an area where there is more available room (17%).

S: If um... the water had soaked it all up then there might be too much concentration of it... water, 'cos there might be less um room in the water so it

moves into the sultana where its got more um room to move about.

10F

<u>Proposition 22: Outward nett movement of water from the cell will occur if the cell is in a solution containing a lower concentration of solutes than the cell.</u>

Eight students (45%) demonstrated misconceptions in this area. Four different types of misconception were elicited. Of these, two categories contained only one student's response.

<u>Misconception 22(a)</u>: A relatively higher concentration of solutes in extracellular fluid will damage or destroy the integrity of the cell (33%).

I: Can you tell me what's happened to the cell in the salt solution?

S: Salt could start breaking it down and pulling it apart in some way.

I: Salt starts pulling it apart. How does it do that?

S: Salt could start eating away at the blood cell.

I: Why does that happen?

S: 'Cos the salt is more concentrated than the blood cell.

1F

<u>Proposition 23: Inward nett movement of water will occur if the cell is in a solution containing a lower concentration of solutes than the cell.</u>

Five of the students (28%) interviewed demonstrated misconceptions of this proposition. There were three categories of misconception, two of which were considered important and are presented below.

<u>Misconception 23(a)</u>: The cell will be unaffected by immersion in the hypotonic solution. (17%)

I: Has anything happened to the red blood cell in water?
S: No.
I: And why do you think that?
S: 'Cos it wouldn't be much different than blood.
17F

<u>Misconception 23(b)</u>: Immersion of the blood cell in water will damage the cell (11%).

S: Umm... it's not the right things that it needs to live.
It hasn't got the right nutrients or whatever that it needs, pH levels and that... so it's floating on the top.
I: Why does this happen?

S: Blood has different components and red blood cells need lots to survive..... so the cell will get smaller.... it will disintegrate and die.
15F

Proposition 24: A large nett intake of water into an animal cell may cause the membrane to burst.

Five students (28%) demonstrated misconceptions in this area. Two different categories of misconception were elicited.

Misconception 24(a): The animal cell will be unchanged by prolonged immersion in a hypotonic solution (17%).

I: Just back to that blood cell in water again. What would happen if it had been left in water for say.. a couple of days?

S: Once there's enough water inside it.. it would probably stay the same.
7F

Misconception 24(b): Prolonged immersion of an animal cell in water will cause it to die due to the absence of nutrients (11%).

I: What do you think would happen to the red blood cell if it had been left in the water for a long period of time?

S: Umm... well it'd die 'cos it hasn't got the nutrients from the blood. But um it would just break down, maybe dissolve in the water... parts would dissolve in the water and other parts just like lay on the bottom

13F

Student misconceptions in the vast majority of categories appear based upon misunderstandings of the random nature of particle motion. Twenty-one different categories of misconception were elicited. 15 of these categories of misconception, (approximately 75%), are founded directly on the notion of non-random particle movement. Students tended to attribute the behaviour of solute particles to causes other than independent, random particle motion.

Of the 15 categories of misconception attributable to non-random particle movement, a total of six different "causes" were provided by students to explain the phenomena they had observed, see Figure 4.

Cause of particle motion	Related categories of misconception
1. An external force	11c, 16b, 21a
2. The movement of the entire body of matter	2a, 3a, 11a
3. To create an equilibrium concentration	3b, 11b, 21b
4. The particles are alive	3c
5. Movement is in the direction of an area where there is more room	16a, 21c
6. Movement is due to the needs of cells	16c, 19c

Figure 4. Categories of misconception in which students attributed various causes of non-random particle motion.

Students' explanations of particle motion vary across the eight concept areas. None of the causes of particle motion listed in Figure 4 are confined to any particular concept area. Each concept area and its related misconceptions is discussed in chapter 5.

CHAPTER 5

Discussion

Introduction

The misconceptions reported in the results chapter are discussed here in greater detail. The types and incidence of misconceptions and their relevance to a sound understanding of osmosis and diffusion are adressed. Previous research that has investigated student understanding of these and related concepts are used to illuminate points of discussion where relevant.

The misconceptions discussed in this chapter have been arranged into the concept areas of particle and kinetic theory, dissolving and concentration difference, and diffusion and osmosis. These concepts provide prerequisite understandings for one another in a logical, sequential manner. The lower order concepts providing the framework upon which knowledge of the higher order concepts may be constructed.

Through sequential discussion of student understandings in each of the concept areas it is possible to isolate some of the sources of misconception of diffusion and osmosis.

Particle and Kinetic Theory

A sound conception of the particulate nature of matter is prerequisite to understanding diffusion and osmosis as the existence and subsequent motion of particles enable the processes of osmosis and diffusion to occur. Understanding the behaviour of submicroscopic particles requires abstract thought processes as particle behaviour cannot be readily sensed. The concrete operational status of many senior high school students can create difficulties in conceptualising this abstract model (Comber, 1983; Garnett, Tobin & Swingler, 1985).

A large proportion of the Year 12 students interviewed in this study demonstrated acceptable understandings about the notion of matter being composed of submicroscopic particles. No misconceptions were elicited regarding this proposition and only 17% had incomplete levels of understanding. This indicates that misunderstandings about the particulate nature of matter are not responsible for student misconceptions of osmosis and diffusion in this sample.

Significant levels of misconception were evident when student understanding of continuous particle motion and random particle direction were investigated. Less than 50% of the students interviewed could explain that particles were continually in motion. Incomplete understanding of this process was demonstrated by 28% and a further 28% held misconceptions of particle motion.

Almost all of the students with misconceptions of particle motion thought that particles did not move independently. The general misconception was that particles would move only if the entire body of matter was moving. This point of view appears consistent with a concrete operational understanding of the motion of particles, where the student has failed to conceptualise the action of the unseen particles. Instead, particle motion is perceived in accordance with the movement of what can be readily seen by the student. It is common for students at this level of understanding to believe that non-observables do not exist (Gilbert et al., 1982). In this study, students believed that particles of water move only when the water in the glass was moved.

Novick and Nussbaum (1981) reported similar findings with research into the understanding of particle theory by university and senior high school students. Less than 50% of students understood the concept of continuous particle motion.

The concept of particles moving in completely random directions appears to be a significant area of difficulty for many of the students. Sixty-one percent of students had misconceptions of Proposition 3, which explains that the motion of particles is in random directions.

Several types of misconception of Proposition 3 were elicited. Five students (28%) felt that particles would only move in the direction that the entire body of matter was moving. Three students (17%) felt that particles would move in a particular direction in order to establish an equilibrium concentration or to occupy an area where there was "more room". Similar responses were evident in misconception categories 11b, 16a, 21b and 21c. This type of misconception reflects an anthropomorphic view of the world where particles are imbued with human characteristics in deciding to move in a particular direction to achieve some purpose (Gilbert et al.,1985).

Propositions 11 and 16 investigated student understanding of random particle motion as applied to solutions. The movement of particles within solutions was similarly attributed to the movement of the entire body of matter, the need to establish an equilibrium concentration or the need to move towards an area within the solution where more room was available.

Similar findings have been reported in relevant science education literature. Doran (1972); Friedler et al. (1985); Novick and Nussbaum (1981) and Westbrook and Marek (1991) have all reported that students hold misconceptions about the concepts of constant motion and random movement. Sheperd and Renner (1982) stated that only 5% of North American senior high school students held sound conceptions of the kinetic theory of matter. It

would appear from the literature that student misunderstandings about particle and kinetic theory are frequent, significant and international.

Simpson and Marek (1988) identified the concepts of random movement and even particle dispersal due to random movement as essential for a sound understanding of diffusion. It is clear that the Year 12 students interviewed in this study do not hold sound scientific conceptions of random particle motion. Instead, students attribute other causes to the motion of particles or fail to recognise that particles move independently at all. Consequently, the misunderstandings of particle motion held by students appear to be prime sources of student misconceptions about the processes of diffusion and osmosis.

Dissolving and Concentration Difference

The concepts of dissolving and concentration difference are fundamental to the processes of diffusion and osmosis. This is because both processes occur across concentration gradients within the solutions comprising the internal and external environments of living organisms.

The concepts of solute, solvent, solution, concentration, water as a solvent for life processes and common solutes in living organisms were all investigated during student interviews. No student held misconceptions of any of these concepts. Relatively low frequencies of

incomplete understanding were demonstrated for these concepts, indicating that these were not areas of difficulty for students. It was only when the notion of random molecular movement was investigated in relation to these concepts that students were found to have difficulty.

Research into student understanding about dissolving and concentration has elicited common misunderstandings about the molecular basis of solutions (Friedler et al., 1985), solvent and dissolving (Comber, 1983) and solubility (Lavoie, 1989). Student misconceptions of these concepts were mostly evident where understanding was probed in relation to the random motion of particles.

The process of dissolving is dependent upon the random motion of particles across an area of concentration difference so that eventually, particle distribution will be even. If students do not fully comprehend the phenomenon of random motion it is logical that they could not fully understand the process of dissolving. Consequently, the process of diffusion in living organisms can not be fully understood as this is dependent upon the random motion of dissolved particles in solutions.

Diffusion and Osmosis

Although 72% of students were able to define diffusion and osmosis at least partially, most were unable to explain the molecular basis of the two processes or incorporate random motion into their responses. Similarly, poor

understanding was evident when students were asked to apply an understanding of these processes to explain or predict what would occur in different biological instances.

Not one of the students interviewed held sound understanding of Propositions 13, 14, 15 or 16. These statements described aspects of the molecular nature of diffusion. Additionally, Proposition 13 and 14 related the process of diffusion to cell physiology and function.

The inability of students to conceptualise the molecular basis of diffusion has also been described by Marek (1986), Simpson and Marek (1988), and Westbrook and Marek (1991). These authors have attributed lack of understanding of the abstract nature of the process of diffusion to the concrete operational status of the subjects interviewed. The operational status of students was not investigated in this study. A significant proportion of Western Australian Year 11 students have not yet attained formal operational thought (Garnett et al., 1985). It was expected that a significant proportion of the Western Australian Year 12 population would also have failed to attain formal operational status.

Student conceptions of osmosis are also limited by lack of understanding of the abstract conceptions of continuous and random particle motion. Friedler et al. (1985) investigated the understanding of osmosis by grade 9, 10 and 11 Israeli school students. They found 32% of

the sample explained that molecules were randomly distributed in a solution. Significant misconceptions were reported regarding molecular movement and osmosis. As in this study, Israeli students provided anthropomorphic and anthropocentric conceptions of both particles and processes, that is, to attribute human characteristics to particles and explain processes in terms of personal experiences.

It is clear in both the literature and this study, that processes not readily observed by students are not fully understood. The concepts of continuous particle movement and particle motion in random directions are two such abstract processes that are poorly understood by the student population. Misconceptions of these processes are evident in this study and those completed elsewhere.

Results indicate that lack of understanding of continuous and random particle motion is responsible for the frequent student misconceptions of the molecular basis of the processes of diffusion and osmosis. It is speculated that the basis of misconceptions include the concrete operational status of the sample population, lack of concrete representations, poor explanations of the processes by teachers and lack of personal experience dealing with the concepts.

CHAPTER 6

Summary and Conclusions

Introduction

The major research question addressed by this thesis asks "What misconceptions of the processes of diffusion and osmosis can be identified in a sample of Year 12 Biology and Human Biology students?" It was evident from both this research and the relevant literature that student misconceptions about diffusion and osmosis are both frequent and relate to unscientific understandings of the nature and behaviour of sub-microscopic particles.

Sound understanding of the processes of diffusion and osmosis is fundamental to many important processes studied in school science. The completion of all the objectives of Year 12 Biology or Human Biology is not possible without these prerequisite understandings.

This chapter summarises the concept areas in which students held sound understanding as well as the most frequent misconceptions of diffusion and osmosis held by the student sample interviewed. It also describes some of the implications these findings have for both teaching and future research. The limitations of this study are also addressed.

Summary of Findings

The knowledge deemed necessary for a thorough understanding of diffusion and osmosis was defined as a sequence of propositions. Student understanding was investigated using an interview - about - events methodology. Student responses were coded as sound understanding, incomplete understanding or misconception. For the purpose of this study, student misconceptions were deemed significant when held by greater than 25% of the sample interviewed.

Three concept areas were identified in which greater than 50% of students demonstrated sound understanding. These included the concept of matter being composed of particles, the concept of a semi-permeable membrane, and the related concepts of solvent, solute and solution.

Significant levels of misconception were evident in relation to 10 of the 25 propositions investigated. Almost all misconceptions were based on poor understanding of the random nature of particle motion.

It is clear that students do not consider the motion of particles to be continuous, random or independent. Instead, particles are often seen as alive and achieving some purpose, such as the establishment of equilibrium, through their movement.

Unscientific "causes" of particle motion were elicited from four of the concept areas investigated.

The most frequent misconceptions of particle motion were:

a) particles do not move independently, they will only move when the entire body of matter in which they are contained, moves;

b) particles will only move in particular directions in order to establish an equilibrium concentration throughout the body of matter; and

c) Particles do not move in random directions, they move in specific directions due to some external force.

Other causes of non-random particle motion, elicited less frequently, were that the particles were alive, particles move to areas where there is more room and particles move to satisfy the requirements of cells.

This research indicates that student misconceptions about diffusion and osmosis have their basis in misunderstandings of particle motion and kinetic theory. The possible origins of these fundamental misconceptions are many and varied. The abstract nature of particles and their behaviour may be incomprehensible to many concrete operational students. Teaching may focus upon a

superficial understanding of biological concepts at a macroscopic level rather than the molecular basis of these processes. Teaching may also fail to present fundamental science concepts in a way which appears simple and plausible to students.

Implications for Teaching

If the small sample interviewed is representative of the population then it would appear that misconceptions are common within the population of upper-secondary students of Biology and Human Biology and that these form a significant part of the foundation knowledge that contributes to student learning. In order to teach important concepts in Biology and Human Biology effectively, the educator must ascertain the alternative frameworks held by students prior to instruction. Subsequent teaching must be designed to bring about the necessary conceptual changes, to eliminate existing misconceptions and foster the construction of scientifically sound understandings.

Teachers must ensure students have a complete understanding of the nature of particle behaviour prior to instruction about higher order science concepts. To be most effective, instruction must suit the reasoning ability of learners (Garnett et al., 1985). Hence, concrete representations such as demonstrations of Brownian Motion, diagrams, models and dynamic computer graphics (Blackmore & Britt, 1993) may provide effective experiences and make the

characteristics of particle motion more accessible to students.

It is also necessary for the teacher to present new information in ways that will be perceived by the learner as both interesting and important. This type of instruction is likely to be actively processed by the learner and incorporated into long-term memory.

Students will need to be provided with opportunities to describe their existing ideas of particle behaviour, osmosis and diffusion. These conceptions need to be evaluated and tested against others by the student. If recognised as logical and plausible the conceptions are more likely to be constructed into memory in the desired manner. Alternatively, if the student's conception is perceived as illogical, the student will be more likely to seek a plausible conception.

Teachers must evaluate their personal conceptions of particle behaviour, osmosis and diffusion. The list of propositions developed and validated in this study would provide a useful checklist for this purpose. These propositions need to be embedded in appropriate language and pedagogy if they are to be accessible to students through instruction.

Implications for Further Research

This study needs to be replicated with a larger sample size and the results of these interview studies could be used to generate a pencil and paper test. This could then be used in the classroom to ascertain student alternative frameworks prior to instruction.

Action research is needed to develop conceptual change learning experiences to foster the construction of scientifically valid understandings. Such studies may involve the development of computer assisted instructional packages incorporating dynamic graphics.

Limitations of the Study

The small number of students, teachers and schools involved in this study may limit the representiveness of the sample and hence the generalisability of research findings. The student sample was drawn from four classes, each with a different teacher. This may represent small variety in teaching style and background. It is also possible that the instructional approaches used by the teachers in this study may not be typical of the population of science teachers.

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APPENDIX 1

Interview Schedule Focus Questions and Diagrams of Events

The interview schedule used primary focus questions which were stated during each interview. These are marked with an asterisk. The subsidiary questions which follow each primary question were only asked when the student response invited their use. The interviewer attempted to use the student's own vocabulary at all times. Diagrams showing outline sketches of the events being discussed were provided at appropriate stages to allow students to draw in the required responses.

Event 1: Glass of Water

(A glass of water was shown to the student to stimulate discussion)

* In your own words, can you tell me what makes up the water in the glass?

What is the same about the water and all other matter?

* Can you draw these particles in the picture for me?

Diagram of glass of water.

* Can you explain for me what these particles might be doing?

Why do the particles move?

How do the particles move?

Where are the particles moving to?

Could you draw some arrows on some of the particles to show me where they are going?

Why do the particles go in those directions?

Can the particles go anywhere else?

Why / why not?

* Imagine that this glass of water has been left here for 24 hours. What has happened to the water?

How do the particles get out of the glass?

Why do they move out of the glass?

Could you draw in these particles for me?

Can you put arrows on them to show me where they are going?

Do any of the particles move back down?

<u>Event 2: Sugar Cube Placed in the Glass of Water</u>

(A sugar cube was dropped into the glass of water).

* Can you tell me what is happening to the sugar particles?

Why do they move through the water?

Can you draw the sugar particles in where you think they might be?

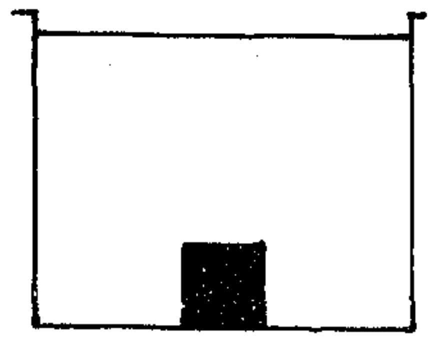


Diagram of a sugar cube in a glass of water.

Why are there more around the sugar cube?

Could you put arrows on these particles to show the directions they are moving?

Why are they moving in these directions?

* Imagine that the sugar cube has been left in the water for 6 hours. How would your picture of the particles look now?

Why has this happened?

Would the particles be moving?

Why would they move?

Where would they move?

Event 3a: Dry Sultanas and Sultanas Soaked in Water

(A glass of water containing soaked sultanas and a glass containing dried sultanas were presented to the student).

* Tell me in you own words, what has happened to the sultanas in the water?

How has the water got into the sultanas?

Why does the water move?

Does anything move out of the sultanas?

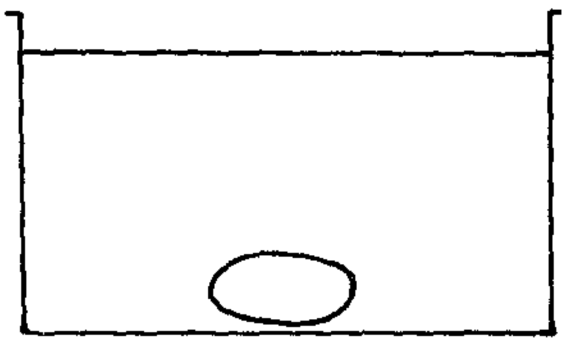


Diagram of a sultana in a glass of water.

Event 3b: Tasting the Water in which the Sultanas Soaked

(The interviewer tastes the water in which the sultanas have been soaked and remarks on how sweet it is).

* Why does the water taste sweet?

How has the sugar got into the water?

How can the sugar leave the sultana at the same time as water enters the sultana?

Why does this happen?

* Draw in particles of water and particles of sugar, use arrows to show the directions the particles could move.

  Why do they move these ways?

  Would the diagram look the same from the time the sultanas enter the water to the next day?

  Why / why not?

Event 4: Red Blood Cells in Water, Blood Plasma and Concentrated Salt Solution

(An outline of a red blood cell as it would look in blood plasma was shown to the student).

* Can you draw in what the red blood cells would look like in water and a concentrated salt solution?

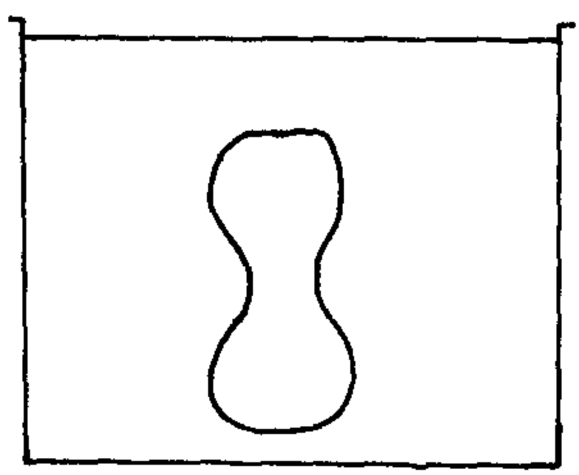


Diagram of a red blood cell in blood plasma

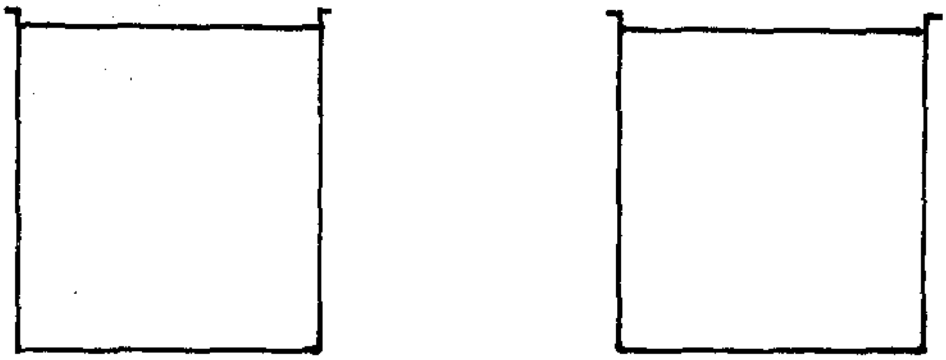


Diagram showing a container of concentrated salt solution and a container of water.

* What has happened to the blood cell in the water?

Why has water entered the cell?

How does this happen?

Why doesn't this happen to the other cells?

* What could happen to the blood cell if it is left in the water for a long period of time?

What causes this to happen?

* What has happened to the cell in the concentrated salt solution?

Why has this happened?

What will happen to the cell after a long period of time?

* Is anything happening to the cell in the blood solution?

Why or why not?

Why are particles moving in this particular direction?

Can you draw in for me the things that are moving and show their directions with arrows?

Event 5: The Cell Membrane

(The interviewer points to the cell membrane of the blood cell).

* What is this part of the cell called?
* What is it like?
  Why is it like this?
* What sort of things can go across the cell membrane?
  How do they get across?
  Which way do the particles go?
* Can any type of particle get across the membrane?
  Why or why not?
* If we wanted to speed up the rate at which particles move across the cell membrane, what sort of things could be done?
  How would these things change the rate of movement across the membrane?

Event 6: Diffusion and Osmosis

* Can you explain for me what you understand by the term diffusion?
* What do you understand by the term osmosis?
* How are these two terms the same and how are they different?

APPENDIX 2

A transcript of the interview with student 6F

I In your own words, can you tell me what you think makes up the water in the glass?

S Makes up the water?

I Yes. Don't forget it's only in your own words, I'm not assessing you in any way. It's just your ideas I'm interested in.

S Is it molecules?

I Molecules, okay. So what would be the same about water and all other matter do you think?

S That they're made up of little molecules, everything's made up of molecules.

I Great. Can you draw in some of those molecules, some of those molecules in the glass. Where do you think they would be? Just a simple representation would be fine. (Pause while student draws.) Okay that's great.

S Do I need to draw a glass?

I No. Can't you tell (laughing) that's my beautiful glass (pointing to the outline of a glass on the student's page.) Can you explain for me what you think any of those particles might be doing?

S (Pause.) Just sitting there.... I don't know.

I Just talking about an individual particle. Is it stationary or is it moving do you think?

S Moving... I think...... depends if you move the glass.

I So when would it move, if it moves ? Just to clarify that for me a bit.

S Um.....if something outside.... like something outside um ... something moved it you know.

I If we moved the glass?

S You know, if it's in its natural environment, you know gravity.... going down.

I So do you mean if the water moves the molecule would move? Is that right, the water would move?

I I see what you mean. Okay, so if we were just talking about the glass now and one particle.. is that moving at all ?

S (Pause.) At the moment, um... doesn't look like it's moving...no.

I Okay... imagine I've left that glass of water in the sun for say.. 24 hours. What would happen to the water in the glass?

S Some of it would evaporate.

I What do you mean by evaporate?

S I think that the water has changed from a liquid to a gas.

I And how does that happen?

S Um.. it's been the sun like... the sun's rays heat it up and change it..... it's changed its form.

I Do think you could explain for me how the sun's rays cause it to change its form.

S Probably by heat.

I Heat... okay so the particles, they have been heated up and that changes them to a gas. Is that right?

S That's what I think anyway.

I Let's consider an individual particle that has evaporated. What would happen to that particle? That molecule?

S Changed to a gas molecule.

I Does it change in any other way or...

S I don't know.

I Um... just trying to think... to work out how it would get out of the glass.

S How it would get out?

I Mmm.

S Like, if it's a gas it would probably float out.

I And why does it do that?

S 'Cause it's lighter than air.

I Mmm... do you think you could draw in a couple of those particles evaporating for me. Just what you think.

S Including the sun's rays or...

I No, just the particles.... You can put an arrow on them for me to show me where they're going. (Pause while student draws.) Okay do any of those particles move back down?

S I'm not sure.

I Do they go in any other directions? (Except upwards.)

S S'pose they could go that way or that way (pointing left and right).

I But they can't go back down?

S If they're heavy... too heavy for air they probably could.

I When would that occur, do you think?
I Okay. So I'll just try to... do you think you could just give me an overview of that so I can see what you think... so they evaporate and they turn into a gas And what happens then?

S Mmm... the gas could either turn back into a fluid.

I And what would the particles do then?

S Turn back into a water molecule.

I And where would it be?

S It'd probably lean back... it'd probably go back down 'cause it's too heavy for air so it would go back in the glass.

I Okay, let's imagine that one did turn into a gas. What would that one do?

S Just float around... up and down.

I Okay.

S Or it'll disappear.

I Alright. We'll go onto another one. (Pause while new items are shown to the student.) Sugar cube here. I'll just drop into the glass. Can you tell me what you think is happening to those sugar particles?

S Dissolving.

I What do you mean by dissolving?

S Changing from a solid to a liquid in the water.

I Let's imagine the individual sugar molecules. What would they be doing?

S They'd be...... they'd be changing from a solid to a liquid.

I The molecules would be mixing with the water?

S S'pose.

I Why would they mix with the water?

S (Pause.) Because there's um...... 'cause it, because the water's there so it has to... take up its space somehow. You know.. like it's got no where else to go so it has to mix with the water.

I Okay, let's imagine an individual sugar molecule. What would that be doing?

S Is that question the same as before or different from before or...

I Sometimes I say the same sorts of questions a couple of times just so I'm sure of what your answer is.

S (Pause.) Is it dissolving in the water?

I Can you draw in the sugar particles for me where you think they would be in the glass?

S What.... after they've dissolved.

I Mmm hmm.

S Does it have to be like to scale you know?

I Oh no, just like..

S And their direction or anything.

I Yeh, you can put arrows on them to show where they'd be going if you think they'd be going anywhere.

S (Pause.) And they'd probably get heavy I s'pose so they'd float back down the bottom.

I Okay.. then those sugar particles go anywhere else or not?

S What, like out of the glass?

I Um.. not necessarily. I was more or less thinking about in the water.

S Um... I s'pose if you mix it around it would go 'round the glass.

I Okay, and why has the sugar molecule moved back down there ? (Pointing to the student's drawing.)

S It's probably too heavy.

I Too heavy. If it's too heavy why has it gone up there (to the top of the glass) do you think?

S (Pause.) Mm.. 'cause maybe like when it's dissolved it's light and when it goes to the top its changed its form and gets too heavy.

I How would it change its form?

S (Pause.) Right.... like chemically or something like that.

I So would it.. do you think it would react with something else?

S Yeh, probably.

I Okay. Imagine that we've left that sugar cube in for say 6 hours. How would your picture of the particles look now?

S (Pause.) It'd probably.. just like a liquid down the bottom of the glass.

I Right.

S Lying down the bottom of..... it's thicker than the water.

I And why does that happen?

S (Pause.) What... why is it down the bottom?

I Mmm hmm.

S 'Cause it's too heavy.

I Too heavy. Okay. Would the particles be moving?

S Why they're down the bottom?

I Mmm hmm.

S I don't think so.

I Okay, we'll go onto the next one (interviewer shows student the next card). With these magic sultanas that I'm so proud of (laughing). There we go. I've got some sultanas there that have been soaked in water and I've got the same sultanas but without being soaked in water. Do you think you can tell me what you think has happened to the sultanas that have been soaked in water?

S They've expanded.

I Okay. And how have they done that?

S The water's probably got into them.

I Right.

S I think.

I How has the water got into the sultanas?

S Osmosis.

I Osmosis... what do you mean by that?

S Well.. the water has gone through the membrane... of the sultana... it's gone through there in from the glass or from outside right into the sultana.

I Why does the water move like that?

S (Pause.) Um... 'cause it's what ... moving from a weaker solution into a stronger solution. 'Cause the water's weak and whatever's in the sultana's stronger.

I But why does the water move though ? What causes it to move through?

S (Pause.) It'd be 'cause the pressure outside is too strong perhaps.

I I'm not sure. What do you think?

S Well, that's the only reason I can think of. It's probably too... the pressure's too strong outside.. it has to equalise or go somewhere else.

I Sorry... what sort of pressure do you mean?

S Um... like the space for the water.

I Like a space?

S Yeh.

I And it goes into the sultana because of what?

S Because there's nothing in.. there was not as much in the sultana as there was outside the sultana.

I Okay, can anything move out of the sultanas?

S Mmm (pencil drops on the floor).

I No worries. I've got another one (hands student another pencil).

S It looks like something has moved out, not.... the water looks a bit... ah kind of yucky.

I That might be just 'cause it's been there over the holidays.

S Oh yeh, a bit dirty.

I If I was to lift the lid of that jar, (with distended sultanas in it) which I won't because it's so grotty, the water inside tastes quite sweet. What do you think has happened?

S The interiors from inside the sultana have moved out of it, into the water.

I How had that material got into the water?

S Active transport.

I Active transport. What do you mean by that?

S The particles from inside the sultana have moved out of the sultana into the water.

I And how's that happened?

S (Pause.) I don't know.....

I You're not sure?

S No.

I Okay. Just wondering if you can explain to me how you think the water can get into the sultana at the same time as some things inside the sultana leave?

S (Pause.) Oh.... I'm not sure about that one.

I Not sure? That's okay. Do you think you might be able to draw in some... some of that material you've been talking about, that made the water sweet, and some of the water particles for me. Just like you did in the other ones (drawings) and put some arrows on it to show me where you think they'd be moving to.

S In this one? (Pointing to diagram.)

I Yeh, that one.

S These are sultana particles (pointing to particles drawn in).

I Okay.

S Water particles (pointing again).

I Okay.

S Just... go in.. well they're crossing like the membrane thing.

I I think I understand what you mean in your diagram.

S Uh huh.

I With the sultana particles, can they move back into the sultana?

S (Pause.) No, I don't think so.

I Why do you think that?

S 'Cause the particles are too big to cross back in.

I To cross back in. Okay, and the water particles that go back in to the sultana, can they go back out again?

S (Pause.) Oh... I'd say that they could if the part of the sultana particles are big enough or they could go through there and the water particles are smaller than them so they possibly could go back through.

I Right... Why does it happen that they both leave and enter at the same time?

S (Pause.) Maybe because the membrane is only open and able to let them pass at one time.. like its only possible for them to pass at the same time.

I Oh yeh... and how do you think the membrane could operate so that it could work that way? So that they could only pass at the same time.

S (Pause.) Well.. being permeable. I don't understand.

I Okay, I'll try to word it another way. Um.. I think I understood you to say that they can only pass through at the same time. Is that right?

S Mmm..

I Okay, just wondering if you can explain to me why that the membrane would only allow them to pass at the same time?

S Then... 'cause maybe if the part that they... these particles are pretty big so when they go through there there's enough for the water particle could pass back through at the same time.

I So when they don't pass through it wouldn't be as big?

S Yeh.

I Is that right?

S Yeh. Something like that.

I Okay, now that... say we've left that sultana in for a couple of days.. would your diagram look the same in a couple of days do you think?

S Mmm.. probably more passed out.... more water has passed in.

I And why would that happen?

S 'Cause its had extra time so more um maybe the membrane has let more in at the time 'cause its getting... had more time to do it.

I Okay, I'll show you this picture here (of a red blood cell). Something I'm sure you've seen before. Okay, I've got a red blood cell in a blood solution, so it would be plasma, and I've got pure water solution and a very concentrated salt solution. Do you think you could draw in for me what you think the red blood cell would look like in the water and in the salt solution?

S What.. what.. with the molecules passing around somewhere....

I Just at the moment can you draw a simple red blood cell what it would look like in the water and what it would look like if it had been left in salt solution?

S What, with the normal shape of a blood cell?

I Just how you think it would look.

S (Pause.) I can't decide on the...

I Just the basic appearance.

S Mmm.. so crude... its shrivelled up or something.

I Okay... right, I think I understand what you mean. I only want simple drawings so that's fine. With the blood cell in the water, can you tell me what you think might have happened to that blood cell?

S Um.. I think that water has passed in through it so it's made it, you know, full shape.

I Mmm.. and why has water entered the cell?

S Osmosis I think.

I And how does that cause the water to enter?

S Well the membrane is let the water in.

I Why does it do that?

S 'Cause it's semi-permeable... or permeable...... I dunno.

I If it is semi-permeable or permeable why does that let the water in to make the cell bigger?

S Why does it let it in?

I Mm hmm.

S To um.... that solution in there is stronger than the one out here and so the water has to go in to equalise the solution or it just goes through because water passes from a weaker solution to a stronger.

I Why does it do that? What causes it to?

S I dunno. I think like it's trying to equalise.

I The water's trying to equalise it?

S Yeh.

I Okay, why is that one (the red blood cell in water) different from the other two?

S Because there's more water in here, 'cause it's actually in water. Yeh and there it's in salt and there it's in blood.

I Okay, what do you think would happen to that red blood cell if it had been left in the water some time?

S Probably become even bigger.

I And why would that happen?

S 'Cause its had more time for water to come in.

I Okay, with the salt solution, what happened to that red blood cell?

S I think it's shrivelled up.

I And why's it done that?

S I'm not really sure. I just think it's 'cause it's what salt would do to something like that.

I Why does salt do that?

S (Pause.) I'm not really sure. 'Cause maybe its taken over the water.

I Taken over the water. What do you mean?

S I don't know. I just sort... of like.. hmm.....

I With the blood cell in the salt solution what do you think would happen to that cell after some time?

S Probably shrivel up even more. Probably die.

I And why would it die?

S 'Cause the salt's not the proper environment for it.

I Mmm.. is that the reason why it's shrivelled do you think?

S Mmm..

I Is anything happening to that cell in the blood solution? (Long pause waiting for a response.) With that blood cell is there anything entering or leaving it?

S Mm.. there's probably some water going into it. Um.. taking the water that it needs.

I And why would that happen?

S For the same reason that that one has... 'cause that's what it does.... that's......

I That's what what does?

S Like this one (referring to the cell in salt solution) what I said about this one.

I What did you say about the membrane shrivelling, is that what you mean?

S 'Cause that's that way it happened, that's the normal...that's just what happens with water. Goes in there to equalise or to.. yeh, to equalise.

I Does anything leave the cell?

S Mmm.. yeh probably wastes and...

I And why do they leave?

S 'Cause it has to get out of the body.

I Why does it leave the cell?

S To get in... mm..... because... it's hard to say um...

I It's all right.. just in your own words.

S Well, it has to leave the blood cell so the blood cell can take it out of the body.

I What causes that? That's what I'm sort of trying to get at. What makes it move out?

S Maybe the water's taken its place and it has to get out. There's not enough room for it.

I Right.

S Mmm..

I Okay. I think I understand what you mean. This part of the cell here (pointing to the membrane), can you tell me what that part of the cell's called?

S (Pause.) That's the..... bit wasn't it? (Pointing to the inside of the cell).

I No, I just mean the whole outline.

S The membrane.

I With that membrane, what do you think it's like?

S Very thin.

I If I were to look at it under a very strong microscope what do you think we would see?

S Well, I'd expect to see little holes or gaps there. Where the particles can pass in and out of. Really small holes.

I Why do you think it's like that?

S To allow molecules or whatever to pass in and out.

I What sort of things can.. do you think.. can go in or out?

S Mmm... all things that they need, things go in.. things that go in and then...... the things that go in are the things that are needed for the body.

I Mm hmm.

S Like oxygen, glucose and all that. Things that go out are sort of things.. are wastes like carbon dioxide.

I How do they get across the membrane?

S Osmosis... no, no.. active transport.

I Can you explain for me what you mean by active transport?

S The way molecules pass from one, from a... yeh molecules pass from a weak solution into a stronger solution... or particles.

I Do these particles go both ways or do they only go one way across the membrane?

S Like... like why.. like wastes?

I Yeh.. well, say wastes.

S The wastes would only go... yeh the wastes would only go out.

I They wouldn't go back in?

S Only if they're going to be... like they'd have to... they'd have to get in there somehow and they'd have to be taken out.

I Can any sort of particle get across that membrane?

S (Pause.) Any sort of particle... um..

I I'll use another example which might be a little bit easier um to envisage. Imagine the gastro-intestinal tract and the microvilli. Imagine all the sorts of food going through. You've got small.. say um salt, little ions, say a potassium ion and a large food molecule, such as a protein molecule. Could've all these got through the cell membrane?

S If.... I don't think real big ones could get through, like proteins.

I Not sure? Why wouldn't they be able to?

S The molecules are too big.

I Too big.

S Or they can't. There's only sections of the body that let the set molecules get through.

I Do all of these particles that get through, do they all move through at the same speed?

S I'm not sure... s'pose they would.

I Right. Imagine you wanted to speed up the rate at which these things get across the cell membrane. Can you think of any things that we might be able to do?

S You could speed up the metabolism in general.

I How would you do that?

S Exercise.

I And how would that affect the speed at which things get across the cell membrane?

S Not... with the blood cell or..

I Any cell. You could think about the blood cell if it makes it easier.

S I s'pose to make it faster for the blood cell you would have to increase the heart rate so the blood's moving faster.

I And how would that affect it?

S If it would affect it?

I The speed of things getting across the blood cell membrane .

S Speed it up I'd say.

I How would it speed it up? What would cause it to speed up?

S The fact that everything's going faster so that has to keep up.

I The blood cell has to keep up so it goes faster.

S Mmm.

I Okay, last question. That would make you relieved (smiling). Do you think you can explain for me, in your own words, what you understand by the term diffusion?

S (Pause.) The passing of molecules from one side of the membrane to the other.

I And why would they pass?

S To either um.. in general.... to um put molecules or nutrients into um the body or to take wastes out of the body.

I Okay, and what do you understand by the term osmosis?

S The moving of water molecules from a weak solution to a stronger solution.

I Solution... and can you tell me what you think is the same about osmosis and diffusion and what you think is different about them?

S The same is that the molecules are passing from a weak solution into a stronger one. The difference is osmosis is water and diffusion is particles of anything really.

I With you moving from a solution of low concentration to... how did you say it again?

I   With you moving from a solution of low concentration to... how did you say it again?

S   Solution... yeh, concentration.

I   Yeh. Where do they move from?

S   From a low one to a high one, I'm not sure, I'm confused (laughing).

I   I think you said it the other way, but I'm not really sure.

S   No, I don't know... I'd say it's from a low one to a high one.

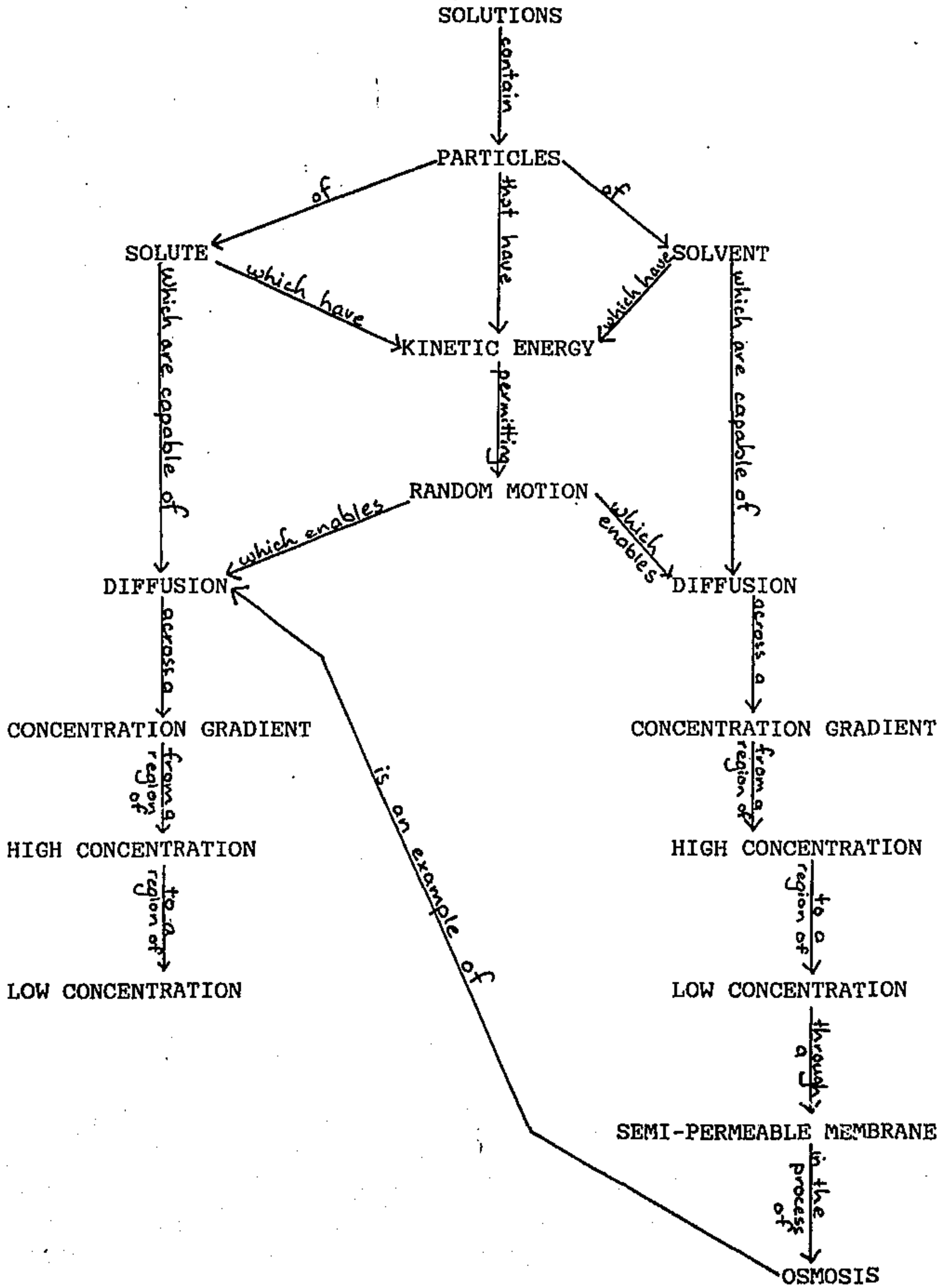
I   And what causes them to move from the low to the high?

S   Mmm just trying to equalise what is.... mm doesn't make... doesn't match now. Oh.. I'd say it would be like trying to equalise up or there's not enough on one side so it moves across to equalise up.

I   Mmm, right. I think I know what you mean. Well that's all I've got for the questions so I'll leave it there.

APPENDIX 3

Concept Map Showing Concepts Required for a Sound Understanding of Osmosis and Diffusion.



APPENDIX 4

Propositions Defining the Knowledge of Osmosis and Diffusion Expected of Year 11 and 12 Biology and Human Biology Students

1. Matter is composed of particles called atoms or molecules and the empty space between them.

2. Particles are continually in motion.

3. The movement of particles in gases and liquids is in random directions.

4. Heating particles increases their kinetic energy and causes them to move more rapidly.

5. Liquids in which other kinds of particles can dissolve are known as solvents.

6. Particles which dissolve in a solvent are known as a solute.

7. Particles of solute and solvent together are known as a solution.

8. In the world of living things, water is the solvent in which many other kinds of particle can dissolve.

9. In the world of living things, oxygen, carbon dioxide, ions, glucose and amino acids are common solutes.

10. The amount of solute dissolved in a certain amount of solvent is known as its concentration.

11. The random motion of solute particles enables them to move throughout the liquid.

12. Diffusion occurs when particles move in all directions by random motion, the nett movement of particles is from a region of high concentration to a region of low concentration, across an area of concentration difference.

13. Diffusion is a slow process and is only effective over short distances.

14. Increased temperature, increased concentration difference, smaller particle size, reduced membrane thickness and increased membrane surface area all act to increase the rate of diffusion.

15. The rate of diffusion will slow down as the concentration difference becomes smaller until the concentration is the same throughout the solution.

16. Movement of solute particles through a solution due to random motion in all directions will eventually cause

nett particle movement to be zero and the distribution of the solute to be even through the solution.

17. A cell membrane is an example of a semipermeable membrane.

18. A semipermeable membrane will allow the passage of some things through it but not others.

19. Cell membranes will generally allow water and small solute particles to pass through them.

20. The size of diffusing particles effects the speed of the moving particle and the rate at which it can diffuse across cell membranes. Smaller particles move more rapidly and diffuse through membrane pores more easily than larger particles.

21. The diffusion of water particles across a semipermeable membrane from a region of high concentration of water to a region of low concentration of water is known as osmosis.

22. Outward nett movement of water from the cell will occur if the cell is in a solution containing a higher concentration of solutes than the cell.

23. Inward nett movement of water will occur if the cell is in a solution containing a lower concentration of solutes than the cell.

24. A large nett intake of water into an animal cell may cause the cell membrane to burst.

25. Nett loss of water from the cell will cause the membrane to shrink inwards.