

Science and Mathematics Education Centre

Teaching and Learning Secondary School Biology with Diagrams

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Doctor of Philosophy
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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature:

A handwritten signature in black ink, appearing to be 'J. Li'.

Date:

13/09/2012

Abstract

This thesis comprises a series of inter-related studies that examined: (1) diagrams presented in commonly used biology textbooks in Western Australian schools; (2) teachers' use of diagrams as part of their normal teaching routines; (3) students' perceptions of how they learn about diagrams in their lessons; and (4) students' use of text and diagrams in explaining two phenomena in biology that had not been presented in class.

Phase one of the research reports the results of an analysis diagrams presented in biology textbooks used by Western Australian students to examine their distribution pattern. Three types of diagrams (iconic, schematic, and charts & graphs) were investigated in science education based on the work of Novick (2006). Therefore, content analysis in this research entailed a systematic reading and categorizing of these diagrams from a number of secondary school textbooks. The textbook types include lower secondary general science textbooks, upper secondary biology textbooks, and biology workbooks. Descriptive statistics were conducted in order to provide first-hand data on exploring how diagrams are used in biology books. Findings of the study suggest that the three types of diagrams are distributed with unique patterns in the secondary biology textbooks.

Phase two reports the investigation of biology teachers' use of diagrams in their classroom teaching. Biology teachers' teaching was observed in order to determine instructional methods related to diagrammatic teaching and learning in the natural environment. This study described and analysed how teachers of biology use the three different types of diagrams to introduce, explain and evaluate abstract biology concepts.

The third phase of the research reports an analysis of how students think about their teachers' instructional strategies when teaching with diagrams. An instrument was developed from a previously existing instrument to help students reflect upon their use of diagrams during their teachers' instruction. The questionnaire data indicated that most participant students recognised teachers' instructional methods in teaching diagrammatic representations as being explanatory tools, in representing biological concepts, and in help assessing their learning. The three dimensions identified by the

questionnaire (Instruction with diagram, Assessment with diagrams and Student diagrammatic competence), demonstrated that students' perceived experienced biology teachers as being more skillful in having diagrams to engage their learning.

Phase four investigated students' conceptual learning of diagrams alongside other modes of representations. The purpose of this phase was to determine how the students interpreted diagrams together with their counterpart – text – when learning three different biology concepts using an interview protocol. In each interview, students were presented with a biological concept with diagrammatic representation (iconic, schematic diagrams, and charts & graphs) together with textual representation (such as written text and chemical equations). The chapter concludes by showing that diagram and text serve different functional roles in students' conceptual learning when one or both representations are presented. The results showed that diagram and text may constrain, construct or complementary each other so as to help students understand the complex concept.

The final chapter draws together and discusses the findings generated in all of the previous studies in which diagrams were used in various aspects of secondary biological education, such as textbooks, classroom instruction, students' perceptions, and representational learning with text. The limitations of the research are discussed and suggestions made for future research on the instructional usage of diagrams in biological teaching and learning.

Dedication

I dedicate this thesis to my parents Liu Gang and Wei Li.

They spared no effort to help me reach the stars and chase my dreams.

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TERMINOLOGY

Multiple representations: an external representation is something that stands for, depicts, symbolizes or represents objects and/or processes. Multiple representations are used to understand, to develop, and to communicate different mathematical features of the same object or operation, as well as connections between different properties. Multiple representations include graphs and diagrams, tables and grids, formulas, symbols, words, gestures, software code, videos, concrete models, physical and virtual manipulatives, pictures, and sounds. Multiple representations are tools for science and mathematics education.

Visual representations: Visual representations translate data into a visible form that highlights important features, including commonalities and anomalies. These visual representations make it easy for users to perceive salient aspects of their data quickly.

Diagrams: a form of visual formatting devices. They can either be pictorial, yet abstract representations of information or abstract graphic portrayals of the subject matter they represent.

Content Analysis: a summarizing quantitative analysis of the content in communication, such as books, websites, newspapers, and laws.

CHAPTER 1

INTRODUCTION

1.0 CHAPTER OUTLINE

This chapter introduces a study into textbooks, teachers' instructional use of diagrams, students' perceptions of teachers' usage and students' use of diagrams in the teaching and learning of secondary high school biology. It begins by describing the framework within which this research is set and goes on to discuss the representational nature of diagrams as a pedagogical tool. Following this introduction, the research objectives are stated and a rationale provided for the study, clearly exploring the significant role that diagrams can perform in biology education.

The significance of this study is outlined in this chapter and then the research problems are divided into a series of research questions that provide a framework for the structuring of this research into four phases. This thesis is composed of a series of studies that investigate how diagrams are engaged in the instruction of secondary biology. Each of these subordinated studies addresses one of the research problems and each is guided by the research questions developed from the research problems. The chapter concludes with a discussion of the limitations of the study and the research problems.

1.1 INTRODUCTION

Scientists create, share, and negotiate the meanings of representations - notes, reports, tables, graphs, drawings, diagrams (Anderson, 1999). In such a case, representations play a central role in explaining scientific concepts to enhance students' learning and understanding and facilitate learners' conceptual learning processes. All these scientific representations have been employed as explanatory tools through which learners contextualize and construct all forms of their knowing.

Representations can make phenomena visible to learners. Pierce's model (Lemke, 2004; Peirce, 1955) provides a theoretical framework of seeing how the explanatory tools such as representations are employed in the process of transmission of

information. Peirce's model proposed some insights on viewing learners' interpretation of concepts as the interplay of a triangular relationship between representation, meaning, and referent in the real world. Ainsworth (2006) argued that the use of representations as an aid to the transmission of scientific ideas is proving to be one of several theoretical accounts relevant to classroom use of representations to support science teaching and learning.

There is growing recognition that conceptual learning is developed through effective use of diverse representational modes (Barsalou, Kyle, Barbey, & Wilson, 2003; Klein, 2006). This perspective places a strong emphasis on the role of representations in learning, implying the necessity for learners to integrate representations with subject-specific conceptual learning in science. Rather than viewing learning as conceptual change brought about by the language of science discourse, cognitive scientists emphasized the fundamental role of the context, perceptions, feelings, embodiment, metaphor, and narrative in learning. Tytler and Prain (2010) suggested that factors such as psychological, cultural, instructional practices and the learning context influence different learners' subject learning. Consequently, attention should be refocused from an emphasis on learners' less scientific conceptual structure to the need of considering both the practices of effective instruction and the diversity of individual learner's competence and skills in interacting with representations (Lemke, 2004). Therefore, in order to learn science effectively students must understand different modes of representations demonstrating scientific concepts and processes, and be able to translate the knowledge learnt from one representation to another, as well as realize the co-ordinated relations in representing expertise (Ainsworth, 2006).

In recent years, studies on multiple external representations have shown that representations can provide unique benefits when students are learning complex concepts (Ainsworth, 1999, 2006). When learners are interacting with multiple forms of representations to learn complex scientific concepts, representations such as diagrams, graphs and written text can provide learners with visualizations of phenomena that are difficult to achieve without such representations. Scientific ideas cannot be separated from their representation, and the learning process implies the need for students to harness the representational usage and to develop their own skills of interpreting scientific phenomena. Lynch (1990, p. 153) argued that "visual displays are distinctively involved in scientific communication and in the very

construction of scientific facts... they are essential to how scientific objects and orderly relationships are revealed and made analysable”. Therefore, representational learning environments require careful handling because different representations have different implications. Ainsworth (2006) insisted that multiple external representations can play many cognitive roles in learning complex material and these different roles fall into three distinct categories: to complement, constrain and construct. This design, functions and tasks framework for learning with multiple representations provides some insights into considering how multi-representational systems might be designed to support learning.

Classification categories of representations generally include textual, visual, mathematical, figurative and gestural, or kinaesthetic (Hubber, Tytler, & Haslam, 2010). Along with other visual modes of representations, diagrams have been eloquently noted as critically important in science education (Lynch, 1990). Hegarty, Carpenter, and Just (1991) classified scientific diagrams into three categories: iconic, schematic, and charts and graphs. Iconic diagrams are defined as providing a depiction of concrete objects in which the spatial relations are isomorphic to the referent object. Schematic diagrams are abstract diagrams that simplify complex situations by providing a concise depiction of their abstract structure. Charts and graphs typically depict quantitative data. The more complicated information draws diagrams that are more abstract, hence the diagrams have to be carefully selected for the particular pedagogical purpose they are trying to achieve.

Larkin and Simon (1987) used the term diagrammatic representation to refer to a set of symbolic expressions in the problem solving process. They believed that the diagrammatic representation preserves explicitly the information about the topological and geometric relations among the components of the problem. In particular, the expressions of diagrammatic representation correspond to the components within a diagram in order to describe the problem. Each expression contains the information that is stored at one particular locus in the diagram, including information about relations with the adjacent loci.

Novick (2006) emphasized the importance of domain knowledge for learners’ correct interpretation of diagrams. For example, having been classified under the schematic category, a cladogram is a hierarchical ladder that is specific to demonstrating

information about biological classification based on common ancestry. Novick provided evidence indicating that the cladograms could be difficult to comprehend especially for students with weaker background knowledge. With the aid of diagrammatic representations, students should be able to better fulfil their learning of biological content knowledge and be able to communicate the mathematical ideas underlying the scientific phenomena. Indeed, there has been a recent call to incorporate instruction in diagrammatic reasoning into the curriculum, particularly for learning macroevolution (Catley, Lehrer, & Reiser, 2005) .

There is a broad consensus in the literature on representational teaching and learning in science that students need to develop an understanding of diverse representational modes if they are to develop a strong understanding of how the instructional use of representations demonstrate science concepts. Recent research in this area has focused variously on the conceptual learning across multiple representations in different topics (Parnafes, 2005), and students' self-construction and explanation of diagrams (Ainsworth & Iacovides, 2005), and the role of visualization in textual and diagrammatic interpretation (Ainsworth & Loizou, 2003).

1.2 THE RESEARCH PROBLEM

The purpose of this study was to investigate how secondary biology textbooks, teachers and students present or use diagrams to improve the teaching and learning of abstract biology concepts. The study identifies the setting and types of diagrams used by textbooks, classroom instruction, students' perceptions on teachers' teaching, and cognitive roles of diagram and text in students' interpretations. The findings of the study could provide some insights for biology educators about the incorporation of different types of diagrams used in biology teaching. This thesis is substantially different from most studies in the field of multiple representations research, as it addresses the topic of diagram use by teachers and students in predominantly natural settings of classroom activity. A variety of perspectives were engaged in this study that not only include the school biology textbooks and teachers' everyday instructional use of diagrams, but also describes students' perceptions on teachers' instructional practice as well as examining the cognitive roles that diagrams and text may have in students' understanding of biological concepts. The study provides

recommendations for practicing teachers and textbook design concerning the appropriate and efficient methods of diagram-inclusive instruction in biology education, with particular emphasis at the senior secondary level.

The broad purpose of this study has four phases as described below:

Phase 1: Investigating the diagrams that students are exposed to when learning secondary biology concepts.

Phase 2: Observing teachers' instructional use of diagrams in helping students make sense of particular biological content such as genetics and cellular respiration.

Phase 3: Investigating students' perceptions of biology teachers' instructional use of diagrams.

Phase 4: Exploring how diagrams correlate with textual representations in helping students develop their understanding of biological concepts.

1.3 RATIONALE

There have been an increasing number of studies documenting the pivotal roles and functions of graph-related representation practice in science (Lynch, 1995; Pozzer-Ardenghi & Roth, 2005). Previous studies produced different results about the content analysis of science textbooks where images or inscriptions were used. In addition, these studies developed their own ontology of graphs and their findings indicated that there were significant differences in a number of aspects such as the total number and frequency based on the specific ontologies. Some studies have emphasized the qualitative differences between the uses of graphs and associated captions and main text that appeared in the high school textbooks and scientific journals (e.g., Roth, Pozzer-Ardenghi, & Han, 2005). Some studies reported the numerous features between graphic and non-graphic illustrations in scientific disciplines (Lemke, 1998; Pozzer & Roth, 2003). However, no study has been found to specifically focus on diagrammatic representation and examine the usage of these representations in secondary science textbooks. Therefore, there is a need for the study to determine the scientific classification of diagrams used in biology textbooks.

There is also a strong research interest in the links between science teaching activity, teachers' pedagogical knowledge, meaning-making process by students, and representational choices that support science teaching and learning in the classroom. Among the various kinds of teachers' knowledge, Shulman (1987) provided the substantial and essential framework for a knowledge base of teaching including pedagogical content knowledge. Knowing students' perceptions can enable researchers and teachers to appreciate the perceived instructional and environmental influences on teachers' teaching process. This research is guided by semiotic perspectives of science as a multi-modal discourse, where learning entails integrating meanings across different modes (diSessa, 2004; Lemke, 2003), social-cultural theories of science learning as induction into the knowledge production practices of science communities (Ford, 2008). The use of diagrammatic representations in the normal biology classroom setting is expected to be dependent upon a range of factors such as explaining content knowledge, evaluating students' learning, teacher experience, and the abstractedness of the concept under study. However, from a teaching perspective, the matching pedagogy to guide teachers' instructional practice in the diagram-inclusive biological teaching environment is still not well established. As there is a lack of research indicating the appropriate methods of engaging different diagram types into biological education, biology teachers' instructional use of diagrams may begin with classroom observations that describe some characteristics of these factors on diagrammatic teaching.

Knight and Waxman (1991) advocated the importance of investigating students' perceptions of teachers' cognition because they provide rich information for understanding students' cognition and classroom processes. Learning is influenced by many educational factors, including students' perceptions of the appropriateness of the learning environment (Fraser, 2012), teaching and instructional styles, teachers' knowledge and cognition about metaphors, images, practical knowledge and events (Carter & Gonzalez, 1993). Using students' perceptions can enable the researcher to appreciate the perceived instructional and environmental influences on students' thought processes.

Research on students' perceptions of teachers' teaching includes effective teaching, perceptions of mastery learning, and co-operative learning (Turley, 1994). From the students' perspective, a good teacher should know the subject well, explain the

concepts clearly, makes the subject learning interesting, appreciates regular feedback, provides extra help to students, and etc. Furthermore, in another study Lloyd and Lloyd (1986) further emphasized students' existing content knowledge that teachers' teaching should fit students' understanding level, so the teacher should provide a sense of how the constituent parts of a discipline fit together. Similarly, Turley (1994) found that students' perceptions of effective teaching were a combination of methods, strategy repertoires and delivery skills, and gave adequate structure and direction. Knight and Waxman identified three areas of students' perceptions of classroom processes, namely, specific strategy instruction, generic teacher behaviours and the classroom learning environment. Specific strategy instruction focused on teachers' direct instruction using specific cognitive strategies; teachers' generic behaviours focused on the effective teaching behaviours that promoting students' learning; the classroom learning environment focused on the classroom atmosphere generated by teacher and student interactions. Consequently, it is worthwhile to develop an instrument that could be used to identify and evaluate students' perceptions of teachers' instructional use of diagrams. Meanwhile, the instrument can also help biology teachers understand how their diagrammatic instructional methods may be recognized by their teaching and how their classroom teaching could be improved based on these students' perceptions.

Research in science education has focused strongly on the representational demands of this subject as a crucial aspect of learning (Ainsworth, 1999, 2006, 2008b; Hegarty et al., 1991; Novick, 2006). From this perspective, students need to understand and conceptually integrate different representational modalities or forms in learning science and reasoning in science (Ainsworth, 1999; Lemke, 2004). These studies believe that, to learn science effectively, students must understand different representations of science concepts and processes, and be able to translate these into one another, as well as understand their co-ordinated use in representing scientific knowledge and explanation-building.

Categories of representations generally include diagram and texts. The comprehension of the diagram and text displays is usually task-oriented and based on different sign systems (Schnotz, 2002). The facilitation of visual displays on learning from text can be explained by Paivio's dual coding theory (Clark & Paivio, 1991). According to this theory, textual information and visual information are processed in

different cognitive sensory systems: a verbal system and an imagery system. Words and sentences are usually processed and encoded only in the verbal system, whereas images are processed and encoded both in the imagery system and the verbal system. Thus, the simultaneous conjoint processing of textual information and visual information could make the learning easier for learners to make cross-connections between the two different codes and later retrieval information.

Mayer (2005) proposed a model of multimedia learning that combines the assumptions of dual coding theory with the notion of multilevel mental representations. Mayer believed that the individual processing of verbal and pictorial information results in the parallel form of mental models that are finally mapped onto each other. The individual selects relevant images or text, and organizes the selected pictorial information into a visual and verbal mental of the situation respectively. It would seem that both Paivo and Mayer's models are based on separate cognitive systems and there is a lack of attention spent on addressing the difference of a range of visual representations. As in these studies, the pictorial representation was referred to as the only mode of visual information that is to be coded by visual coding systems. It would seem appropriate to consider other types of visual displays, such as diagrammatic representations, dynamic video clips, etc.

With more effort placed on diagrams, Ainsworth and Loizou (2003) depicted their experiment by using metacognitive strategies that can help learners develop deeper understanding with text and diagrams. The experiment asked participant students to self-explain the information they obtained about the biology topic – the human circulatory system. Their results show that students who learnt from diagrams performed significantly better than students given text. These authors argued the benefits of self-explanation were much greater in the diagrams condition. The study showed that diagrams could promote the self-explanation effect, the semantic differences between the interpretation of diagram and text, and the cognitive affective and cognitive properties of the text and diagrams studied. Though the diagrammatic representation was analysed with reference to students' explanation of biological content knowledge, the learning effects of diagram and text were measured and compared separately. However, rather than testing the outcomes of quantitative measures, there is a lack of research that adequately gives emphasis to

the representational principles of the cognitive roles that diagram and text play in the process of students' interpretation of a certain biological concept.

1.4 SIGNIFICANCE

The research described in this thesis has significance in four areas, namely textbook design analysis, teachers' instructional behaviours, evaluating students' perceptions of teachers' diagrammatic usage, and cognitive roles of diagram and text in students' conceptual learning. While the research is part of the growing international interest in the representational teaching and learning studies relating to science education (see e.g., Ainsworth, 2008b; Eilam & Poyas, 2010; Moreno, Ozogul, & Reisslein, 2011; Waldrup, Prain, & Carolan, 2010), this study is one of the few pieces of quantitative studies to date that describes how diagrams are used by textbooks, biology teachers' classroom teaching, and students, rather than measuring the learning outcome generated by employing different modes of representations. While both types of studies are required, this type of research permits detailed directions to be opened in the analysis of diagram-inclusive instructional materials. The observation of teachers' teaching that is reported in this study allows for a better understanding of how different types of diagrams are engaged in the classroom teaching. The quantitative survey could be practically valuable as a tool for gathering students' perceptions that may guide biology teachers in refocusing their teaching practices. The interpretative analysis of students' cognitive processes provides another perspective on investigating the interaction of diagrammatic and textual representations.

The study of content analysis can provide guidelines to biology textbook authors on how to structure and present diagrams so that they can better demonstrate different levels of biological learning. The study also encourages textbook designers to fully consider the representational features of diagrams so that the biology concepts can be better understood by secondary students.

The influence of the study upon diagrammatic teaching practice could be considerable. Though biology teachers may agree that diagrams could serve as an important tool for students to make sense of the content knowledge taught in class, many may have inadequate pedagogical knowledge about how diagrams can be used for different purposes in biology teaching. Most teachers organize their own

diagrammatic teaching based on their personal experience. Therefore, the outcomes of observations that is reported in the study can provide some insights for biology teachers in regard to their diagrammatic usage in everyday teaching activities.

The instrument evaluating students' perceptions could be valuable for researchers and teachers because it provides them with a validated tool for gathering information on important aspects of students' perceptions of teachers' instructional use of diagrams. The information obtained by the instrument in regard to students' perceptions could guide classroom teachers in refocusing their teaching practices. It is likely that the study could add to the literature of classroom learning environment about measuring students' perceptions of biology teachers' instructional use of diagrams.

The study proposed new functional roles that may apply to the adjunct diagram and text that were engaged in students' biological learning. Results of students' conceptual learning revealed how visual and textual information are processed. The findings from this study can make several contributions to the current literature on human cognitive system interacting with a combination of diagrammatic and textual representations. The functional roles of diagram and text may serve as a framework for understanding the cognitive science of multiple representations. The utility of this framework is proposed to be useful in identifying the cognitive roles that influence biological learning, revealing a number of factors in the multiple representation learning environments especially when diagram and text were employed.

1.5 PHASES OF THE STUDY AND RESEARCH QUESTIONS

The study comprised four phases, each of which examined the one or two of the five research questions which are restated below as study headings. Chapter 4 through 7 each describe a phase of the thesis study. Specific research questions relevant to each of the phases have been presented below:

Phase 1: Investigating diagrams that students are exposed to when learning secondary biology concepts.

A content analysis was conducted with the aim of investigating the different diagram types that students are exposed to in their everyday biology learning. The aim of

content analysis is to check the availability of various types of illustrations been used in explaining biological concepts. In addition to that, the distributional features of diagrams were explored through the examination of a number of teaching materials, such as textbooks and student workbooks. Nine textbooks were closely examined for the presence of diagrams. The textbooks used had been identified by state syllabus organizations as current, generally used textbooks for Australian senior secondary science and biology education. The diagrams were classified based on the classification criterion recommended by Novick (2006). Analysis was made of the frequency with which different types of diagrams occurred in the different sections of textbook and different textbook types related to the lower and upper secondary science and biology textbooks. Besides all the biology textbooks and workbooks, some lower secondary general science textbooks were also included in the analysis. Because these books comprise of many science subjects for junior year students, whereas the contents not only biology but also chemistry, physics and natural science are all contained. This phase of the study is reported in Chapter 4 and addresses Research Questions:

1. What kinds of diagrams are students exposed to in textbooks and workbooks when learning science and biology in senior high school?
2. How are diagrams distributed in textbooks?
3. What are the development trends of the diagrammatic usage in the textbooks?

Phase 2: Observing teachers' instructional use of diagrams in helping students make sense of particular biological content such as genetics and cellular respiration.

Of particular interest to the researcher was the role of diagram-inclusive instruction and the actual teaching process with diagrams in the everyday secondary biology classroom teaching. Consequently, in keeping with the qualitative approach for research into teachers' and students' use of diagrams, an interpretive design (Erickson, 1986) was used to address this interest. The qualitative data collected in this study included field notes, teachers' teaching materials and audio tapes of lessons during teachers' instruction. Teachers' instructional methods of teaching diagrams were analyzed in the investigation of how diagrams are incorporated in the

everyday biology teaching. The phase of the study is reported in chapter 5 and addressed the following research question:

4. How do teachers choose to use different types of diagrams when teaching secondary biology?

Phase 3: Investigating students' perceptions of biology teachers' instructional use of diagrams.

This phase describes the development of an instrument suitable for the assessment of students' perceptions of teachers' use of diagrams in the classroom setting. The researcher deemed it important that such an instrument be designed in close association with identifying students' perceptions regarding instructional use of diagrams in their biology class. Before administering the questionnaire, the development of the instrument required several stages, starting with identifying the salient characteristics of the teaching approaches. By analyzing the results from administration of the questionnaire, teachers can examine how those factors are employed in the instructional use of diagrams in biology teaching process. The phase of study is reported in chapter 6 and addressed the following research questions:

5. What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?
6. What are students' perceptions of teachers' instructional strategies with diagrams?

Phase 4: Exploring how diagrams correlate with textual representations in helping students develop their understanding of biological concepts.

In this phase, the researcher developed an interview protocol, in which a number of biological concepts are illustrated with different types of diagrams and written text. The interviewing procedure is designed to elicit students' interpretation from two sources of diagram and text respectively, and then to compare and analyse how the information relates to each other. By relating to the theoretical framework and

previous research findings, it is intended that this stage will reveal how the three different cognitive functions exist between students' interpretation of diagrams together with text. This phase of study is reported in chapter 7 and addressed the following research question:

7. What are the roles that diagrams and text have when learners relate both representations to understand biological concepts?

1.6 LIMITATIONS OF THE STUDY

Several issues have been identified here as limitations of the studies in this thesis. Finding schools that are willing to accommodate the researcher for conducting classroom observations of this type is often difficult. Preferences were given to those experienced biology teachers who were more enthusiastic about demonstrating their instructional strategies with diagrams. While research involving teachers such as these is valuable to the findings of the study, caution needs to be exercised when considering the generalizability to other school systems and less professional teaching staff. In addition, the presence of the researcher in the classroom may have influenced teachers to be more careful in their content use and their pedagogical approaches. However, the presence of the researcher should have influenced teacher and student behaviour less and less as the observation schedule continued.

The results and conclusions generated in this study refer specifically to the sample groups involved in the study. Generalization of the findings to all secondary biology teaching and learning must be considered with caution due to the nature and the limited size of the samples. The distribution patterns of diagrams in other biology textbooks, the students' perceptions of teachers' instructional strategies, as well as the functional roles of diagram and text were used in learning different biological contents may vary.

1.7 SUMMARY OF CHAPTER AND STRUCTURE OF THE THESIS

This chapter has described the literature of relevant studies, research problems, rationale and significance for the study, and also outlined how the structure of the thesis facilitates the investigation of the research problems. In the following chapter,

issues relating to the relevant theories on representational teaching and learning environment especially when diagrams were used will be fully discussed. Specifically, discussion is brought to focus on the studies regarding to using the diagrammatic representation in science education as well as the individual's cognitive process interacting between diagram and text information.

Chapter 4 through 7 report the four phases of the research. Chapter 8 provides the research overview and discuss the contribution of the thesis to theory building and the implications of the research. Suggestions for future research are provided and comments are made regarding the limitations of the research findings.

CHAPTER 2

LITERATURE REVIEW

2.0 CHAPTER OUTLINE

This chapter reviews literature that pertains to the representational features of scientific diagrams used in the instruction of science subjects. This chapter comprises five major sections: (1) The first section is a discussion of the necessity of exploring the challenges and difficulties in teaching and learning science. Based on metacognitive beliefs, effective learning is the result of the interaction between the new concepts and students' current conceptions. Rather than viewing learners as passive recipients of information, learners are viewed as active seekers and processors of information; meanwhile the external representations can be considered as the medium that conveys the conceptual information. (2) The second section investigates the representational nature of illustrating scientific conceptions. Representations can help learners make sense of biological concepts at various levels: at a phenomenological level, molecular level and textual level. (3) The third section examines particular challenges in teaching and learning biology with visual representations, by referring to the detailed misconceptions existing when visualizing and conceptualizing biological concepts. Among all the static representations, diagrams could serve as explanatory tools in the process of transmission of information. (4) Section four specifies the typology that has been employed in classifying the diagrams in science teaching and learning. In addition, the instructional functions of diagrams together with their counterparts are elaborated. (5) Section five reviews the theoretical framework of the study and the functional roles of multiple representations. The theoretical framework of this study drew upon Ainsworth's taxonomy on the educational value of multiple representations engaged in teaching and learning complex scientific concepts.

2.1 INTRODUCTION

Scientists create, share, and negotiate the meanings of representations - notes, reports, tables, graphs, drawings, and diagrams (Anderson, 1999). This claim serves as a

good example when reading and writing are viewed functionally as tools for representing and understanding the meaning of science. All these scientific means of representations have been employed as explanatory tools through which learners contextualize and construct all forms of their knowing. In such a case, representations have played a central role in explaining scientific concepts to enhance students' learning and understanding and facilitate learners' conceptual learning processes.

Researchers now broadly agree that the discipline of science should be understood as the development and integration of multi-modal discourses (Lemke, 2003; Norris & Phillips, 2003) in which different modalities serve different needs in relation to reasoning and recording scientific inquiry. In particular, cognitive psychologists and computational scientists have described some commonalities in learning with multiple external representations. For example, according to de Jong et al. (1998), learners have to evaluate and select these representations of information and to integrate them into their personal knowledge construction process when confronted with different types of representational information. Eilam and Poyas (2010) emphasized the need of developing students' system thinking performance when learning from visual representations.

Representations can make phenomena visible to learners. Much recent research on learning with representations generally has focused on students' identifying design features of representations that act as an advance organizer to promote conceptual learning (Schnotz & Bannert, 2003; Waldrup et al., 2010). The influence of learning with representations has been closely related to the investigation of domain knowledge. Meanwhile, these applications and advances in multiple representations research have affirmed the enormous potential to promote the value and significance to the learner.

Along with other representations, diagrams are found to be ubiquitous in science teaching because they are important tools for the conceptual communicating and reasoning of structures, processes, and relationships (Whitley, Novick, & Fisher, 2006). Roth, Pozzer-Ardenghi and Han (2005) concluded that research on graphical displays have largely been conducted from two theoretical approaches. The first approach mainly focuses on cognition located in individual minds and mediates

between individual's notions and experience. The second approach places the emphasis on the role of culture and social practice in representational teaching and learning activities. These two theoretical approaches might also suggest that there may be a chasm between particular modes of visual representation with science subjects such as biology taught at school. In this study, the researcher took the former cognitive position by exploring the properties inherent in the diagrammatic displays and the knowledge as a capacity constructed in the learner's mind. As a mode of visual representation, learning science with diagrams is grounded in the conceptualisation of knowledge as a tentative human construction widely known as constructivism that insists conceptualisation is reflected in constructing the new knowledge on a prior conceptual framework. In addition, emphasis has to be placed on how a learner's thinking changes when engaged in the diagrammatic learning process.

2.2 CHALLENGES AND DIFFICULTIES IN TEACHING AND LEARNING SCIENCE

All science subjects seek to provide representations and explanations for natural phenomena in order to describe the causal relationships and the complexity of the natural world (Gilbert, 2007). Such descriptions of complex phenomena have usually been chosen to correspond to the learners' formation of visual perceptions of what happened in the real world. Visualization then becomes vital in making abstractions visible and providing the basis for understanding the scientific explanations of entities, relationships, causes and effects phenomena. However, transitions between different levels of representation are difficult for students to make (Gilbert, 2007), because they are not able to move into and between the modes of representation with the fluency that may be expected of them (Kozma, 2003).

2.2.1 LEARNING SCIENCE AS METACOGNITION

The importance of metacognition for regulating and supporting student learning has been promoted by educational psychologists and practitioners. Metacognition is used to depict cognition about phenomena or simply "thinking about thinking" (Flavell,

1979, p. 906). The very diversity of multiple representations requires learners to gain awareness of the features that are essential for individual understanding (Eilam & Poyas, 2010). Subsequent development and use of the concept of metacognition in education have remained relatively faithful to its original meaning. For example, Cross and Paris (1988) defined metacognition as the knowledge and control students have over their own thinking and learning activities. Hennessey (2003) saw metacognition as awareness of one's own thinking, awareness of the content of one's conceptions, an active monitoring of one's cognitive processes, and an attempt to regulate one's cognitive processes in relation to further learning. More recently, students' self-regulating and controlling features have been emphasized in accepting scientific ideas and in problem solving. Kuhn and Dean (2004) insisted that metacognition is about the awareness and management of one's own thoughts; Martinez (2006) elaborated on this as monitoring and control of thought. Metacognitive teaching and learning emphasized the knowledge and skills are gained through learners' self-regulation of their own cognitive processes.

One of the important features of metacognitive learning is the active role of learners in managing their inquiry learning process. According to de Jong et al. (1998), three paradigms dominate the field of learning and instruction. The first paradigm is *constructivism* whereby students should be encouraged to construct their own knowledge instead of memorizing information based on authority. The second paradigm is *situationism* which simply emphasizes that students need to learn in realistic situations instead of learning in decontextualised, formalised situation such as learning occurs in the classroom. The third is *collaborative learning* which is about students learning together with others instead of on their own. Cognitive theories have shifted the focus of functioning from environmental variables and onto learners, especially in interpreting student's learning for understanding such as how they retrieve, encode, process, and store information (Schunk, 2008). Consequently, learning is more considered as an active process of seeking and processing information, rather than being passively to have the target information received.

2.2.2 METACOGNITION AND CONCEPTUAL LEARNING

Research in science teaching has shown that children's metacognitive abilities are essential to conceptual change in science (Hennessey, 2003). Metacognition is thinking about one's own thoughts, that is, being aware of one's conscious and deliberate thoughts (Gilbert, 2007). Hennessey's work demonstrates that teachers can help students become more metacognitive so that they can improve their conceptual understanding of science. Through the process of conceptual change, learners' metacognitive understanding of a science concept involves *self-monitoring* and *reflection* on learning (Abell, 2009). Therefore, students' conceptual learning is the metacognitive understanding of the concept.

Metacognition can support student learning and understanding of many subjects (Abell, 2009). With a constructivist perspective to the conceptual change theory, students actively accept new ideas through collaboration and consensus building of new conceptual understanding. Indeed, teachers work hard to help students achieve the goal of accepting the new understanding through a process of conceptual change, and in the process, students regulate their own thinking. Hennessey (2003) found two levels of metacognitive thought:

- A representational level – a display of one's inner understanding.
- An evaluative level – illustrated by drawing, mind mapping and thus to examine learners' ideas.

The process of learning is closely associated with the process of metacognition (Hennessey, 2003). Learning through intentional conceptual change indicates that students are aware of their own learning and how they learn, which gives more responsibilities for achieving successful learning. This position is in line with Skemp's (1976) argument that representational level related to learners' schema of knowledge been reflected in their level of understanding.

Furthermore, metacognitive learning strategies offer an evaluative means for the comparison of scientific ideas and initial science ideas and discussion of ideas with others (Duschl, Schweingruber, & Shouse, 2007). Keogh (1999) introduced the metacognitive teaching strategy whereby students were able to demonstrate their conceptions using concept cartoons. Students using these concept cartoons actively

regulate their own learning and teachers investigate and promote students' learning, thereby achieving conceptual change.

2.2.3 CONCEPTS, CONCEPTIONS, AND REPRESENTATIONS

Strike and Posner (1992, p. 148) explained differences between concept and conception that “ we used the word conception to mark the plurality and internal complexity of these objects of change, and to distinguish it from the term concept as used in normal discourse.” A concept is defined by two meanings: one concerns classification of objects with names and one is about the knowledge that an individual has (White, 1994). Therefore, a concept is closely related to other concepts in an individual's cognitive structure and thus scientific concepts must be consensually accepted by the learners.

White (1994, p. 118) defined conceptions as “systems of explanation” that can be regarded as the learner's internal representations constructed from the external representations of entities constructed by other people. Duit and Glynn (1996) considered conceptions as learners' mental models of an object or an event. It can be suggested that representations are the ways we communicate ideas or concepts by representing them either externally – taking the form of textual or verbal forms, pictures, or physical objects or a combination of these forms or internally when we think about these ideas (Hiebert & Carpenter, 1992). The broad debate about the general nature and tasks of representational learning has revealed much about the role that representations play in students' learning.

Recent research interests on learning science with representations has focused on either identifying key design features of effective representations that act as advance organizers to promote successful student interpretation and learning (Ainsworth, 2006) or analysing the conditions under which students' construction of representations promotes learning (diSessa, 2004). Moreover, other theoretical accounts of meaning-making relevant to conceptual learning in science and classroom practice use a representational focus to develop a framework in supporting student learning (Waldrip et al., 2010).

2.2.4 METACOGNITIVE TEACHING RESOURCES AND STRATEGIES

Metacognition is the process of learners consciously using strategies to enhance learning. There are four aspects of metacognitive monitoring described by Hacker (1998): a) Metacognitive knowledge – an awareness of what the learner does and does not know; b) Metacognitive experiences – personal experiences that can be applied to the learner's knowledge; c) Goals/ tasks – an understanding of the demands of the task; d) Actions/ strategies – an ability to make choices of appropriate strategies to achieve the goal. These factors indicate that metacognitive strategies can be integrated throughout instruction. Brown and Abell (2007) recommended a metacognitive learning cycle that includes explicit conceptual status accompany each learning cycle phase. According to Brown and Abell, the learning cycle is based on three phases of instruction: 1) *exploration* that allows students to gain firsthand experiences through the investigation of scientific phenomena; 2) *concept introduction* requires students to build scientific conceptions through interaction with peers, texts, and teachers; and 3) *concept application* that needs students to apply what they have learnt in problem solving activities. It is therefore likely for students to alternate between hands-on and minds-on activities, both of which are necessary for learning science.

2.3 REPRESENTATIONAL NATURE OF SCIENCE TEACHING AND LEARNING

The properties that make visual representations different from each other have been discussed in various disciplines. Differences between representational formats pertain to many aspects: (1) the relation between external and internal representations, (2) the relation between descriptive and depictive representations, (3) the analogical nature of representations, and (4) the explanatory power of multiple levels of representations.

2.3.1 EXTERNAL AND INTERNAL REPRESENTATIONS

External representations are defined as the visualization of the knowledge and structure in environment, as physical symbols, objects, graphs, written languages,

models. The information in external representations can be received and processed by the learner. External representations in this study refer to both graphical and linguistic forms; in contrast, internal representations are knowledge and structure available in memory (Zhang, 1997). The comprehension of a science concept is a process of constructing internal representations on the basis of intentionally created external representations.

Internal representations differ from mental models as they contain more visual-spatial information which is a higher degree of analogical approximation to reality (Greca & Moreira, 2000). As Greca and Moreira further pointed out that the notion of mental model is a type of knowledge representation that is implicit, incomplete, and imprecise, and is incoherent with normative knowledge in various domains. The main role of a mental model is to allow its builder to explain and make predictions about the physical system represented by it. Therefore, a mental model has to be functional to the person who constructs it. Whereas an internal representation would allow the learner to proceed with the construction of a mental model further and act according to the resulting predictions.

Representational conventions. What a representation signifies is established through mutually agreed conventions or cultural agreements (Scheiter, Wiebe, & Holsanova, 2008). The meaning of visualization is imposed onto the representation as it is constructed based on the properties of the objects that has been represented. Thus, for some representations, their meanings are derived from already existing cultural rules as how to interpret their imposed meaning. Palmer (1978) has referred to verbal representations as extrinsic representations from the outside, where meaning is imposed onto the representation from the outside.

Interpretation and reasoning. Iconic visualizations can be intuitively understood by the learner because they are similar to those real-world referents (Gibson, 1979). Because information is grouped in realistic representations, visualizing the central idea could reduce the need of searching for other irrelevant elements. Hence, information can be directly picked up without the mediation of memory, inference, deliberation, or any other mental processes (Zhang, 1997, p. 71). The interpretation of verbal representations requires learners to be explicitly familiar with its meaning in advance, otherwise they could not relate the meaning to the expression (e.g.,

language acquisition). In this case, inferences have to be made through the learner's cognitive processing of verbal representations. Recently, Waldrip et al. (2010) argued that learners' self-constructed representations can function as a thinking tool or scaffold meaning interpretation during its construction, and then serve as an artifact of thinking.

2.3.2 DESCRIPTIVE AND DEPICTIVE REPRESENTATIONS

Representations differ from one another with respect to their informational content and their usability (Palmer, 1978). According to Schnotz (2002, p. 103), a sign system could either be descriptive or depictive. A *descriptive representation* consists of symbols that have an arbitrary structure in which the content is presented by means of conventions - examples are texts, mathematical equations, and chemical equations. A *depictive representation* consists of visual displays of iconic signs that the content can either be concrete or abstract, such as drawings, photographs, and diagrams. Both representations can be used to provide learners with information at either a concrete or a more abstract level.

Depending on the structure as well as the process of operation of the representation, descriptive and depictive representations can be informationally equivalent if both allow the extraction of the same information to solve specific tasks (Larkin & Simon, 1987; Schnotz, 2002). Larkin and Simon (1987) defined computationally equivalent as the same amount of effort spent by the learner in retrieving task-relevant information from two different representations. The informational content could be computational equivalent with respect to their representational structure and the procedures that operate on the structure (Schnotz, 2002). Hence, designing and interpretation of depictive representations require taking into account the interplay of both the representation structure and task-relevant information.

Descriptive representations and depictive representations are differentiated in different learning tasks. The depictive representations have an advantage in encompassing a certain category of information (Schnotz, 2002). For instance, it is advantageous for maps to manifest geographic information. Descriptive representations are much powerful in delivering linguistic meaning, especially for a

cluster of continuous meanings. Moreover, the distinction between descriptive and depictive representations also applies to internal representations achieved by learners (Schnotz & Bannert, 2003). The internal representation of descriptive representation has to be constructed during the learner's processing of the textual representations. The mental representations of both visual images and textual representations are perception-proximal representations (Kosslyn, 1999); therefore it is crucial to consider the ways in which the two distinct representations are employed to represent scientific concepts together.

2.3.3 THE ANALOGICAL NATURE OF REPRESENTATIONS

Analogies prompt a visualization process that aids learning of concepts (Glynn, Britton, Semrud-Clikeman, & Muth, 1989). Science teachers present analogical information to students by using a variety of different representational techniques, such as verbal and written language, graphics and pictures, practical demonstrations, abstract mathematical models and semi-abstract simulations. An analogy is a process for identifying similarities between different concepts. Because scientific concepts are alien for students to understand, analogical features are commonly used to provide visual links to familiar concepts and provide a foundation on which students can build scientific conceptions. In general, an analogy is more often associated with an explanation of science content, such as when a familiar entity is used to provide information about, interpret or communicate ideas about a less well known entity. The instructional representations that have analogical features embedded are in line with the constructivist approach to teaching. Therefore analogies used by science teachers are found to be one or several forms of representation to help teaching and learning of abstract science concepts, reasoning and problem solving, and for conceptual change (Linsey, Wood, & Markman, 2008).

Drawing on the previous research findings on other subjects of science education such as chemistry, Chittleborough and Treagust (2008) argued that the metaphorical nature of representations provides links to familiar domain knowledge on which students can build new concepts. It was noteworthy to see that Gilbert (2008) used the term 'analogical transfer' to emphasize the bridging effects of helping learners build connections between different modes of visualizations. In particular, some

other studies further identified the analogical transfer between diagrams and models (Chittleborough, Treagust, Mamiala, & Mocerino, 2005; Yaner & Goel, 2006). Given the important attributes of analogical visuals in scientific instruction and reasoning, representations can be used to illustrate the biological domain knowledge that students encounter.

The prerequisite for students to construct a coherent mental representation is originally formulated for learning with analogies but can be adopted to the linking process between different types of representations (Seufert, 2003). In the biology classroom, visual analogies are frequently used and validated by juggling between students' familiar experiences and the target concepts (Treagust, Harrison, & Venville, 1998). In particular, Middleton (1991) reported a number of biological units illustrated by metaphorical sketches and diagrams in terms of everyday entities. Evidences include cells – a city with a government, roads and business; body systems – factories processing and transporting materials; and genetics – a painting made of the same colours to produce different works of art.

2.3.4 EXPLANATORY POWER OF MULTIPLE LEVELS OF REPRESENTATIONS

Current theories in cognitive science adhere to multiple representations of knowledge, which advocate using more than one mode of representation in the processes of teaching new science concepts that are often multimodal and complex in nature (Barsalou et al., 2003; Cheng & Gilbert, 2009). Multiple external representations are realistic representations of the targets using one of two formats or modalities such as verbal and visual-graphical formats. Visual technologies and representations on learning and understanding provide critical approach for science education research (Eilam & Poyas, 2008). Research shows that effective understanding is achieved by being able to interrelate among the three levels of representation of matter which are described as being at the:

- Macroscopic level that describes tangible and visible phenotype and bulk properties in daily life.

- Submicroscopic representations that provide explanations at the particulate level like atomic or molecular.
- Symbolic representations that involve the use of drawings, symbols, formula and equations to symbolize matter.

These findings have supported the idea that multiple representations can be beneficial or detrimental to the construction of internal representations that facilitate the communication in the science classroom. Johnstone (2000) emphasised the necessity of starting the teaching with the representations of macroscopic or symbolic levels, because both the two corners of the triangle are of more concrete and thus easier to be visualized. Whereas the sub-microscopic level is the most difficult to understand (Nelson, 2002), for it describes the information that is perceptually compelling rather than visually relevant. Therefore, this level of representation could simultaneously provide strength through the intellectual basis for biological explanations, but it also posed challenges of understanding it.

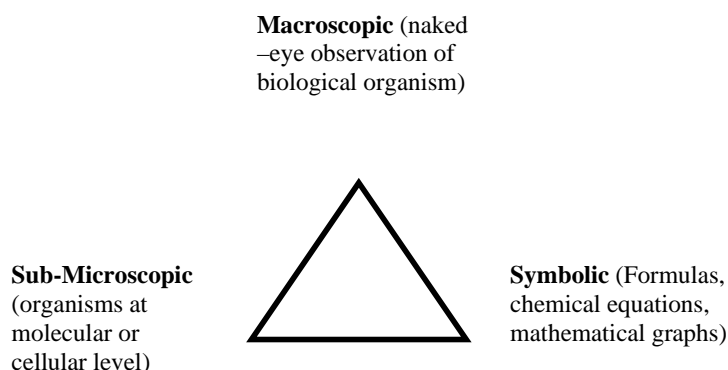


Figure 2.1 Examples of Three Levels of Biological Representations of Organism (Johnstone, 2000).

It is the theoretical nature of the multiple levels of representations that is essential for biological explanations (see figure 2.1). Macroscopic representations describe bulk properties of tangible and visible phenomena in biological experiments of daily experiences when learners observe changes in biological organisms such as the colour changes of tree leaves, the difference between an animal cell and a plant cell. Sub-microscopic representations provide explanations at the molecular level in which concepts are usually elaborated as the microscopic structure of cardiac muscle cells or the magnified transverse section of leaf. Symbolic representations involve

the use of formulas and equations, as well as molecular structure drawings, diagrams to symbolise abstract biological mechanisms.

Findings from other recent studies support this notion of building connections between different representational levels. Wright (2003) claimed the necessity that learners should pay more attention to learning concepts at the macroscopic level and to build mental models between the macroscopic and symbolic levels of representation. In the study of analysing the representations in chemistry, Davidowitz and Chittleborough (2009) revealed that chemical diagrams provide opportunities for learners to construct acceptable personal mental images when the sub-micro level is involved in learning concepts. Engaging multiple representations in learning science is considered as more than a tool for illustrating meaning; it could also serve as an important instructional strategy in communicating content knowledge and facilitating students' understanding of science concepts.

2.3.5 DESCRIPTION OF A BIOLOGICAL CONCEPT AT EACH LEVEL OF REPRESENTATION

Familiarity with these interconnected levels of multiple representations is important for building the integrated conceptual understanding of biology concepts and phenomena. A coherent mental representation and a deeper understanding of the subject matter can be constructed only when learners identify all these references within and between the external representations and subject matter which is represented (Seufert, 2003). In order to be able to achieve the goal of having a holistic understanding when learners are engaged in reasoning about biological mechanisms and other biological phenomena, students should be able to constantly navigate between these levels of representation, utilising each representation at the appropriate stage of their reasoning. Students' successful acquisition of new content knowledge may be attributed to simultaneously dealing with the macroscopic, sub-microscopic and symbolic levels of representation in biology. From observations of changes that occur at the macroscopic level, students may also need to work out these changes at the molecular / sub-microscopic level. The sub-microscopic level in turn is signified through symbols and formulas. Examples of different levels of representation involving aerobic representations are shown in Table 2.1.

Learners always experience difficulty in their understandings of biological concepts shown by different levels of representations. The sub-microscopic level cannot be seen directly, and while the biological concepts have been accepted by students, understanding the sub-microscopic level depends on students' individual transition between different representational levels. For example, students may experience difficulty in understanding the sub-microscopic and symbolic representations in learning the biology topic aerobic respiration because these representations are abstract, intangible and cannot be seen directly. It is not always easy to consider what is happening at different levels of representation based on what has been portrayed by the phenomena, such as explaining the definitions of genotype and phenotype in genetics. Students may often not be able to translate one given representation into another due to their limited conceptual knowledge and poor visual-spatial ability.

2.4 THE UNIQUE DIFFICULTIES IN TEACHING AND LEARNING BIOLOGY WITH VISUAL REPRESENTATIONS

In the constructivist view of learning, students actively construct and re-construct their knowledge on the basis of their existing conceptions. This is often true when the learning of new biological concepts requires students to transfer the shared attributes between the new knowledge and their pre-existing conceptions or experiences. For instance, the teacher may draw surface similarities between students' existing knowledge - *fiddle head* and target knowledge - *sprout of fern* when teaching the vegetative reproduction. Other analogies include *cable wire* for a *vertebrate neuron*.

2.4.1 MISCONCEPTIONS IN VISUAL LEARNING


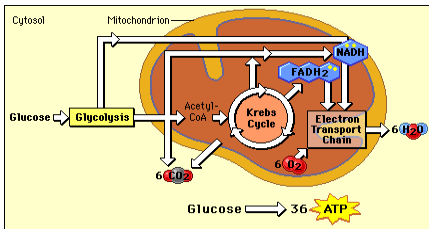
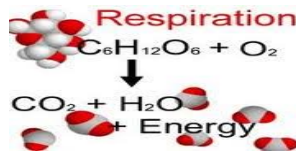
Biology is a difficult subject to understand because it has many abstract concepts that may be in conflict with students' pre-existing knowledge so that students are unable to make sense of the scientific explanations from teacher. Probing and facilitating a learner's understanding of science concepts has been a focus of research in science education (Garnett, Garnett, & Hackling, 1995; Gilbert, 2008). Compared with a number of science subjects, teaching about biological concepts poses a predicament for biology teachers: since biology science is an extremely diversified science subject

that deals with varied organisms (bacteria, plants and animals) and various hierarchical levels of biological organization (molecules, cells, tissues, organs, organisms, populations, and ecosystems). Correspondingly, a wide range of visual representations such as diagrams and other analogical visual representations have been employed in all levels of biology education. Students' misinterpretations on these visuals may occur if representations are not used carefully in the teaching. Therefore, appropriate instructional strategies need to be applied to facilitate learners achieving their representational learning.

Investigating students' conceptions of scientific concepts has become one of the most important domains of science education research. Findings from many studies show that human beings' pre-instructional knowledge or beliefs have a serious impact on their further learning of new concepts (Duit & Treagust, 2003). In addition to the new concepts, students' misconceptions are inevitably generated as they make sense of their direct observations and daily experiences. By examining students' drawings, the alternative conceptions could also be formed as they read textbooks, learn from the illustrations and other representations assigned in the biology classroom (Pozzer-Ardenghi & Roth, 2005; Thiele & Treagust, 1995).

A great amount of literature has investigated the alternative conceptions generated by learning biology with analogies (e.g. Glynn et al., 1989; Treagust et al., 1998; Venville & Donovan, 2007). In addition, students' analogical reasoning ability and visual competence also needs to be taken into consideration because they affect students' performances and learning. In particular, biological education should emphasize an individual's visual learning skills and the ability to apply these skills in his or her lifetime for biological learning, research and problem solving.

Table 2.1 Description of the Aerobic Respiration at Each Level of Biological Representation

Aerobic Respiration	Level of Representation		
	Macroscopic	Sub-microscopic	Symbolic
Biological Mechanism	Aerobic respiration is assisted by animals' muscular movement performed by the breathing and respiratory system.	Aerobic respiration at the single cell level is the release of energy from glucose or another organic substrate in the presence of Oxygen. Oxygen in the air which is necessary for aerobic respiration.	The chemical equation summarises the reaction as: $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 = 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy (ATP)}$
Description	Real life situation and experience like doing exercise and etc. 	The particulate or cellular level according to the biological mechanism. 	A representation that helps to summarize and produce a mental image. 
Perception	Visible	Invisible, but explanation is based on descriptions, diagrams.	The equation is a tool to help understand and memorise the mechanism.

2.4.2 COORDINATING REPRESENTATIONS AND LEARNING

The use of representations to fulfil meaningful learning has been highlighted in the field of biology education. Buckley (2000) asserted that the complexity and multiple levels of organization of biological phenomena are unable to be observed or experienced until representations can play the crucial role in helping students understand those biological concepts. As such, it may be worthwhile referring to the role of multiple representations in chemistry education, because chemistry educators have already drawn attention to the students' misinterpretations in chemistry teaching and learning that can be caused when the links are not built between different levels of representation such as the macro and sub-micro levels (Davidowitz & Chittleborough, 2009). Constructing linkages across different levels of representations requires students to constantly transfer from one level of demonstration to another in order to accept the invisible and abstract chemical concepts. As such, this research had been guided by the notion that learners must direct their own learning as well as understand the various representations and how they relate to each other. It may be the case that understanding biological concepts can be challenging. The difficulty lies not only in interpreting different levels of representations for the biological content depicted, but also in switching and integrating each representation to develop holistic personal mental models of biology knowledge.

Identification of misconceptions or alternative conceptions is an initial step towards better science teaching and learning, for the knowledge of causes of alternative conceptions is essential for designing effective instructional strategies (Schönborn, Anderson, & Grayson, 2002). Based on the nature of biology as well as the analogical features of diagrams, learners' difficulties in learning biology can be broadly classified in macroscopic, molecular, and textual levels:

- (1) Representations at macroscopic level.

Students' learning of biology concepts starts from observing visible phenomenon and tangible entities. Bruner (1962) emphasized the term *general ideas* (i.e. biological principles) that support the structuring of more specific knowledge interpreted from phenomena. Investigating students' interpretation of science concepts at the macroscopic level provides novice students with an excellent starting point.

Thereafter, the subsequent content knowledge is easier recalled and used by the individual.

Photographs are the most frequent type of representations used in secondary biology textbooks (Roth, Bowen, & McGinn, 1999). An implication of this situation is the possibility that a photograph can achieve a powerful role as a representation of the real entity. However, the narrative and perceptual order of interpreting the image may cause misinterpretations for readers. It has been confirmed by Pozzer-Ardenghi and Roth (2005) that photographs are often taken as mechanical records of reality, that is, to serve as guarantors of truthful representation of real world. The abundant amount of information and salient details within a picture help students generate various kinds of interpretations depending on the individual's focus.

Photographs and pictures can serve and make significant contributions to science learning because of their potential for improving learners' retention of associated text (Peeck, 1993). Therefore, learners are less likely to achieve the scientific interpretation of the domain knowledge by making sense of the single meaning-making resource and representation. Another possibility of engendering misinterpretations is that research has shown students prefer textbooks that contain illustrations and inscriptions, namely photographs, caption, maps, tables. However, appropriate and necessary instructions on how to read and analyse photographs are not provided (Pozzer-Ardenghi & Roth, 2005; Pozzer & Roth, 2003). These studies above therefore provide important implications for investigating students' alternative conceptions generated by photographic images at a phenomenological level.

(2) Representations at a molecular level.

The biological entities and processes at a molecular level are inherently complex because students can only observe them under a microscope beyond their direct experience. Unfortunately, only a very limited number of biology structures and processes may be observed under the simple microscope in schools where other more sophisticated equipment like electronic microscopes are not available. Though the learning of biological phenomena and facts are essential for long-term memory, various levels of biological organization cannot be fully explained and understood without examining those processes that are invisible to the eye. Scientific understanding of a particular sub-microscopic process is generally externalized in the

form of a pictorial representation which is a primary component depicting conceptual knowledge of biology (Kindfield, 1993). Students' transition between the macroscopic and molecular representations has proved to be helpful for their conceptual understanding (Cook, Wiebe, & Carter, 2008).

The attainment targets for learning at the molecular level include: fostering systematic thinking and the ability to relate biological phenomena at various levels of biological organisation found to each other. However, students' ability to explain at the sub-microscopic level was found to vary greatly in learning chemistry (Chittleborough & Treagust, 2008), so the same may be the case in learning biology. The value of biological diagrams was demonstrated in their ability to connect ideas and concepts. Particularly, diagrams have a role to play in connecting the macroscopic and sub-microscopic levels of representation. To develop scientific meanings, diagrams and illustrations are universally accepted as being beneficial learning tools in many disciplines (Stieff, Bateman, & Uttal, 2005). Most science teachers use diagrams frequently in their teaching on the assumption that they make things easier for students to understand. However, research suggests that a large number of students have difficulty understanding diagrams (Hartley, Wilke, Schramm, D'Avanzo, & Anderson, 2011). Diagrams usually delete unnecessary and irrelevant information to make the concept being taught more salient. The abstract science concepts and processes which cannot be photographed could therefore be represented in a diagram. Correct interpretation of diagrams requires transforming from one level of representation, and students have been found to have difficulties appreciating the role of the diagrams in explanations (Chittleborough & Treagust, 2008).

For students with little or no background knowledge, diagrams of the sub-microscopic level of representation appeared more difficult to interpret. One of the main difficulties facing learners' interpretation is that they have inadequate knowledge about understanding the symbols and conventions made up of the diagrams (Gilbert, 2007; Tversky, Zacks, Lee, & Heiser, 2000). In particular, the techniques in designing a diagram may include: 1) the diagrammatic information could be exaggerated deliberately or inadvertently (e.g. Lowe, 1986; Wheeler & Hill, 1990); 2) the drawing techniques are utilized (e.g. Schollum, 1983); and 3) high level spatial ability is needed for understanding (e.g. Mathewson, 1999). Similarly,

Henderson (1999) recommended the importance of coding conventions used in reading scientific diagrams. The pedagogical value of diagrams should be considered in regards to their characteristics, purpose and usage. With the intention of making biological concepts easy to be taught and understood, textbook designers deliberately use various conventions to organize images – photographs appear to be taken directly from life, line diagrams appear to be simplified by omitting irrelevant detail, arrows appear to have unambiguous meanings, scales appear to be obvious (Martins, 2002). However, these characteristics are not familiar to all learners and familiarity with these conventions is a prerequisite to comprehending and using images.

(3) Representations at Textual level

The textual level incorporates the qualitative abstractions and quantitative equations used to represent concepts at the macroscopic and sub-microscopic levels. More emphasis should be placed on the role of representation in learning and learners need to pay more attention using their own representational resources to engage with subject-specific science knowledge (Hubber et al., 2010).

It is noteworthy to see that Chandrasegaran et al. (2008) revealed that students also experienced difficulties in understanding the sub-microscopic and symbolic systems of representation in chemistry because these representations are so abstract that the concepts cannot be experienced in person. Biology teaching involves the use of a wide range of representations such as chemical symbols, mathematical formulas, and drawings, as well as biological terminologies to symbolize matter. As the most abstract type of representation, the function of symbolic representation or written language has been suggested as one particular strategy to help students achieve the multiple sense of scientific literacy.

2.4.3 DIFFICULTY IN VISUALIZING AND CONCEPTUALIZING BIOLOGICAL CONCEPTS

Understanding complex biology concepts can be challenging both cognitively and meta-cognitively because learners must direct their own learning as well as understand the various representations and how they relate to each other (Marchionini, 1988). The problem lies not only in the difficulty of seeing various

biological phenomena directly but also in the difficulty of interpreting and relating multiple levels of representations toward acquiring scientific understandings. For example, biology teaching involves the use of a wide range of representations such as chemical symbols, mathematical formulas, and drawings, as well as biological terminologies to symbolize what is being observed. As the most abstract type of representation, emphasising the function of symbolic representation or written language is a strategy to help students achieve the scientific understanding of biological concepts. The necessity of students correlating different levels of representations has also been addressed as a contributing factor for achieving the scientific conceptions (Tang & Moje, 2010).

Students' naïve biological explanations of this concept are formulated through their direct observations and everyday knowledge of daily life. At lower levels of biological organization the tissue and cellular structures that enable organism functioning are too small to be seen unaided and thus are inaccessible to learners without visualization tools (Chi, De Leeuw, Chiu, & LaVancher, 1994). One of the challenges posed by illustrations in biology books is the difficulty of making invisible biological entities and mechanisms "seen" by the learners. Understanding biological phenomena such as how the human kidney filtration functions is difficult for a number of reasons. For example, Mathai and Ramadas's (2009) study of students' responses to questions on human digestive system, students could more effectively learn both structure and function through text rather than through diagrams. As a complex interactive mechanism, it can only be explained at the sub-microscopic level of representation that ranges in scale from the glomerulus to capillaries much smaller than human visual range. Meanwhile, the kidneys are invisibly hidden in the body and their functional mechanisms are always hidden from view. Subsequently, students often develop misconceptions about how kidney structure and function (Ebenezer, Chacko, Kaya, Koya, & Ebenezer, 2010).

Arnaudin and Mintzes (1985) and Patel, Kaufman and Magder (1991) examined the unscientific understandings about the circulatory system held by secondary students and first year college students. The researchers described misconceptions about many aspects of the blood respiratory system that were caused by oversimplified usage of the instructional representations. Such misconceptions illustrate the point clearly that when learners are unable to observe or experience phenomena directly,

representations can play a crucial role in delivering information. In particular, Dwyer (1978) examined the difficulties in learning realistic drawings and photographs, concluding that simple diagrams were more effective than realistic images in helping learners to identify the relevant information.

The category above not only classifies students' difficulties in understanding biological concepts, but also underlines the nature of biological science and education and the importance of acquiring a coherent and integrative picture and understanding of biology.

2.5 INSTRUCTIONAL FUNCTIONS OF DIAGRAMS

2.5.1 DIAGRAMS USED IN BIOLOGY TEACHING

Diagrams are critically important in biology teaching. Previous studies have found that there are numerous images, photographs, diagrams and naturalistic drawings on each page of biology textbooks (Pozzer & Roth, 2003; Roth et al., 1999). Among all those static illustrations, Hegarty, Carpenter, and Just (1991) examined the use of diagrams in scientific contexts, especially in biology teaching. Hegarty et al. categorized scientific diagrams into three categories: *iconic*, *schematic*, and *charts and graphs*. An *iconic* diagram refers to accurate depiction of concrete objects in which the spatial relations in the diagram are isomorphic to those in the referent object. Because iconic diagrams look like what they represent, they are effective in helping students recognize how different kinds of physical systems that are not available to visual inspection (Hegarty et al., 1991). An example is the comparison of the sketches between skeletons of an Asian elephant and an African elephant. The iconic sketches provide visible outlines that could help to infer the differences of their habits of living. *Schematic* diagrams are abstract diagrams that simplify complicated situations by providing a concise depiction of their abstract structures (Lynch, 1990). Schematic diagrams are highly abstracted from real world entities but do not preserve the physical relationships presented in the source information. Examples include electric circuit diagrams, magnetic fields, periodic table. *Charts and graphs* depict a set of related, typically quantitative data and numerical meanings based on interpreting independent variables. For instance, a line graph can depict the relation between the hours of sunshine and the rate of flowering. A pie chart can

show the percentage of water that is contained in a healthy body weight. It is necessary for the reader to identify all independent variables before making an interpretation because abstract meanings and numerical data are embedded into charts and graphs.

2.5.2 INSTRUCTIONAL FUNCTIONS OF VISUALS AND TEXT ADJUNCTS

Visualizations are frequently used in conjunction with written materials in instructional contexts. Some visualisations emphasize the applicability of pictures and text for expressing particular information (e.g., Bernsen, 1994; Mullet & Sano, 1994), or the organizational structures of graphics and text (e.g., Vekiri, 2002), while others show the interplay between human cognitive systems (e.g., Schnotz, 2002). Those studies above provided some insights for this study about investigating learners' interpretation of biological concepts when diagrams accompany text.

A prominent analysis of the instructional functions of visualization with text has been conducted by Levin, Anglin and Carney (1987) who described five functions of visualizations with text: decorative, representation, organization, interpretation, and transformation. Decorative function refers to the visualizations being introduced only to make a text more aesthetically appealing for learners. However, some meta-analysis studies did not support this argument by arguing that presenting irrelevant additional information may distract learners from processing the theme of the intended learning or cause inappropriate encoding schemas (Harp & Mayer, 1998; Levin et al., 1987). Representational function suggests that a certain visual representation has the ability to make the meaning of its related text more concrete. Organization function refers to the visual representations that make learners more familiar with the organizational or argumentative structures of the text (Vekiri, 2002). Interpretation function of visualizations is to make texts more understandable for learners. Hence, these findings may be the reasons why visuals and texts are introduced side-by-side in textbooks and multimedia learning environments.

By emphasizing the information to be conceptualized and learners' memorizing process, Levin et al. (1987) proposed that visualization has a transformation function that could accommodate information through the following three steps: recoding the

information into a more concrete and memorable form; then relating the information to the pre-organized conceptual structure, and finally being ready for retrieving the new information for later use. Eilam and Poyas (2010) argued that revealing and comprehending relations among variables are essential cognitive operations for achieving system understanding in all domains. The most significant finding from these studies is the confirmation that multiple media learning materials could facilitate the transition of a broader and deeper understanding to novel situations.

However, some researchers on multimedia learning have pointed out the limitations of Levin et al.'s finding that relies heavily on the redundant information presented in both textual and pictorial representations (Bobis, Sweller, & Cooper, 1993). Bobis et al. suggested reducing the amount of redundant representational information presented to learners because this may consume more cognitive resources for retrieving and integrating the target information. Though the irrelevant information embedded in the representations is redundant for the learning task, a number of researchers insisted on having a certain degree of overlapping information during representational learning. On the one hand, it is possible to eliminate all those irrelevant information from both the verbal and image descriptions, even if to deliberately make representations informationally equivalent (Kosslyn, 1999; Stenning, Cox, & Oberlander, 1995). On the other hand, Scheiter et al. (2008) believed that the redundant information could be helpful because learners can draw connections between the two separate representations allowing for an coherent internal representation formed up. The important role of redundant information has also been supported by Hegarty et al. (1991) that text and diagrams can complement each other by providing different information about the same object; text can be redundant when the information is given in different formats; however, text can provide specific information to guide a learner's processing of diagrams. The three exact relationships differ according to the specific content and purpose contained by the text. According to Hegarty et al., the notable contributions of integrating text and diagram to the understanding of a scientific topic depends on additional factors such as the nature of information to be extracted and the difference of individuals' ability. A study by Eilam and Poyas (2008) also corroborates the idea that students learn better from the diversity of visual representations than from text only, thereby rich variety of representation-types should be extended to more learning contexts.

Regardless of whether or not the two engaged representations are informationally equivalent or redundant, Ainsworth (1999, 2006) has emphasized that interacting with multiple forms of representation such as diagrams, graphs and equations can bring unique benefits in learning complex concepts. In Ainsworth's (2008b) functional taxonomy of multiple representations (MERs), she proposed three different functional relations between the visual representation and its counterpart verbal representation: complementary roles between line graph and equations displaying value for mass, force, friction and velocity; constraining roles between the interpretation of a single concrete animation and another abstract velocity-time graph; constructing relational understanding in the velocity-time graphs and distance time graph. Although Ainsworth's taxonomy was explained in the context of physics learning through computer simulation environments where the visual representations could be interactive and dynamic, any of these functional roles may apply to other multiple representational learning environments, such as biology.

Ainsworth (1999) suggested there are three key functions of multiple external representations: to complement, constrain and construct (see figure 2.2).

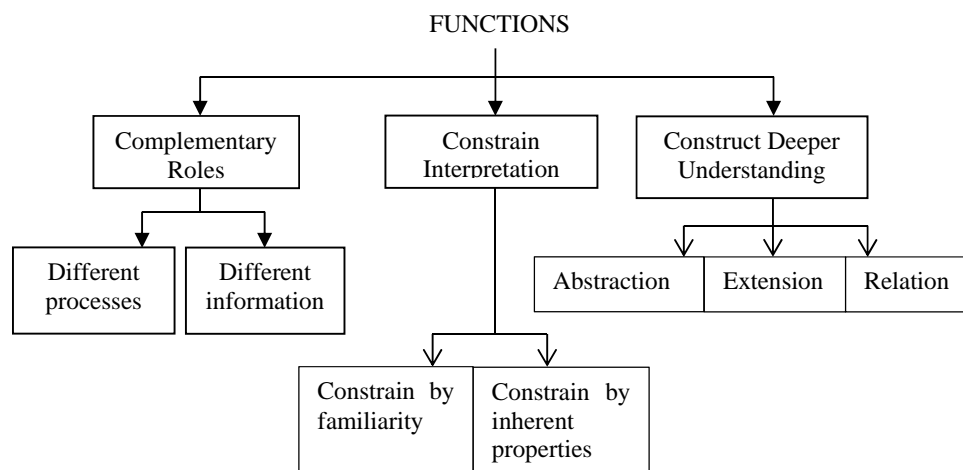


Figure 2.2 Functions of Multiple Representations (from Ainsworth, 1999)

2.6 THEORETICAL FRAMEWORK FOR ANALYSING TEACHING AND LEARNING WITH DIAGRAMS

2.6.1 MULTIPLE VISUAL REPRESENTATIONS

Visualization is defined as representations of information consisting of spatial, non-arbitrary and continuous characteristics (Rieber, 1990). Thus, visualizations could be thought of as a specific form of external representation that is employed to convey visual and spatial information and then to be processed through the learner's sensory system. Visual information typically depends on human perceptual and cognitive abilities to be efficiently and effectively communicated in a learning or problem-solving context (Gilbert, 2007). It can thus be postulated that visualisations are particularly well suited to conveying an understanding of complex visuo-spatial relations that are an important characteristic of many scientific domains.

External representations such as visualizations are defined with regard to their relation to the real world (Scheiter et al., 2008). Palmer (1978) argued that the nature of representation is that there exists a correspondence from objects in the represented world to objects in the representing world. This argument is in agreement with other research that found representations can act as a substitute for the referent and evoke similar responses as the real-world referent by means of analogy (Scheiter et al., 2008). As such, a visual external representation provides a depiction of spatial relations that are isomorphic to the referent object.

Visualizations constitute a major component in multimedia-based instruction, which can be regarded as learning from pictorial and textual representations (Mayer, 2005). These two modes of representations have been treated in a different manner in educational research; the substantial research literature has been conducted mainly concerning the effectiveness of learning with visual representations (Anglin, Vaez, & Cunningham, 2004; Gilbert, 2008). As a consequence, studies showed widely varying results, with learning with different types of visualizations serving either negative or positive results on learning. Despite the significant role of learning with visualizations there is little research about how learners process the semiotic properties of visualization and how visual representations and verbal representations are integrated in teaching. As indicated above, multiple representations may serve different functions depending on the instructional scenarios and content domain.

2.6.2 THE TAXONOMY OF MULTIPLE REPRESENTATIONS FUNCTIONS

Representations have advantages in supporting learning science (Ainsworth, 2006). Research on the benefits of providing learners with combinations of more than one representation has discovered a number of functions in supporting learning. According to de Jong, et al. (1998) there are many reasons for using more than one representation in learning. First, specific information can best be conveyed in a specific representation, while a combination of several representations is likely to display learning material that contains a variety of information; second, problem solving depends on having a large repertoire of representations or mental models, being able to switch between them and selecting the appropriate ones.

2.6.2.1 Multiple Representations in Complementary Roles

The complementary functions of MERs in Ainsworth's (1999) functional taxonomy are to use representations that provide complementary information or support complementary cognitive processes so that learners could benefit from the advantages of combined representations such as teaching with both diagrams and written-textual representations.

Multiple External Representations support learning by providing *complementary information*. On one hand, the multi-representational environments allow learners to concentrate on different aspects of a task so that they can likely achieve their goals in the learning task (Oliver & O'Shea, 1996). On the other hand, how multiple representations can support new inferences by providing partially redundant representations such as a functional diagram of a heating system and a physical map to show the position of its components (Ainsworth, 1999).

Multiple External Representations also can provide *complementary cognitive processes*. According to Ainsworth (1999), firstly, the different representations containing equivalent information can still support inferences. For example, diagrams could demonstrate learners' perceptual processes by classifying the relevant information that then makes conceptual learning easier (Larkin & Simon, 1987). Textual representations could help learners perform spatial judgement more accurately (Tapiero, 2001). Secondly, multi-representational learning environments

present a choice of different representations to cater for the varying degree of experience and expertise of students who have different representational preferences. Thirdly, learners' performance in problem solving was found to be effectively improved when they have been employed in multiple representational learning environment (Moreno et al., 2011).

2.6.2.2 Multiple Representations in Constraining Information

In the functional taxonomy of Multiple External Representations (Ainsworth, 1999), constraining functions refer to introducing a familiar representation to constrain the learner's interpretation/ misinterpretation of a less familiar representation so as to help learners achieve a better understanding of the domain. In addition, the constraints also can be achieved by taking advantage of inherent properties of representations. For example, photographs are always employed in secondary biology textbooks alongside complex and unfamiliar representations such as diagrams or written text: when explaining the term ATP, two modes of representations were employed in Figure 2.3.

Written text: 'ATP consists of an adenine linked to a ribose sugar and three phosphate groups'.

Diagram:

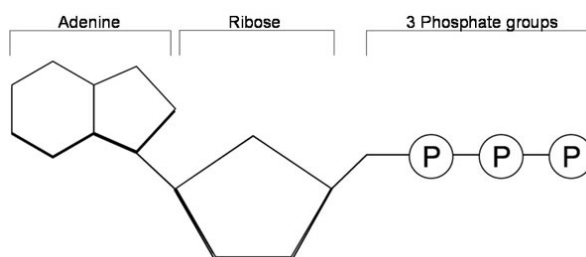


Figure 2.3 Structure of Adenosine Triphosphate (ATP) Shown by Diagram (adopted from teacher's handout).

Though the two representations contain the same information, students may have difficulty in understanding the detailed information solely by reading the text, such as, the exact locations of the three chemical components, and how they are connected. However, Stenning et al (1995) argued that graphical representations contains more specific information than textual representations. Therefore, when both representations are employed, interpretation of the ambiguous (textual)

representation may be constrained by the specific (diagram) representation. As a result, the inherent ambiguity contained within the text could be eliminated by the information provided by the diagram. The literature also confirmed the similar mutual explaining effects between diagram and text.

2.6.2.3 Multiple External Representations in Constructing Understanding

The third function of Multiple External Representations is to encourage learners to construct deeper understanding of a phenomenon through *abstraction* of, *extension* from and developing a *relational understanding* between the representations (see figure 2). The differences between these functions of Multiple External Representations are subtle and all may exist in certain processes.

Abstraction refers to the process by which learners create mental entities that could serve the basis for further conceptual formation at a higher level (Ainsworth, 2006, p. 8). Abstraction also can be conceptualized as the process of detecting the extract features and removing the redundant details through interacting with representations (Giunchiglia & Walsh, 1992). Students construct references across different modes of representations that have the underlying structure of the domain knowledge. This meaning is compatible with ontological conceptual change (Chi et al., 1994). The abstraction function may support learners to switch their understanding between different types of representations and apply their learning in other specific contexts.

Extension is a way of extending knowledge to new situations without fundamentally changing the nature of that knowledge at a higher level (Ainsworth, 2006). Accordingly, within the same domain, the extension involves a learner exploiting an understanding of one representation in order to understand a second representation for the same knowledge. For example, a learner may know how to interpret a photograph in order to determine that cell division for growth is taking place during the mitosis process; subsequently they can extend their knowledge of mitosis to more abstract representations like schematic diagrams and text.

Relational understanding is the process by which two representations are associated without reorganization of knowledge (Ainsworth, 2006). The goal of teaching for relational understanding emphasizes that students' consideration should be placed on

creating the relationship between the two representations that they may already be familiar with. On this occasion, Dugdale (1992) gave an example in constructing understanding between graph and equation.

Though students' interpretation of the information in visualizations is critical to learning, Ainsworth, Prain, and Tytler (2011) argued that learners need to develop representational skills. They further concluded the importance of teachers' and learners' use of drawings - to enhance students' engagement, to acquire visual literacies of representing science, to organize their knowledge more effectively, and to communicate and clarify ideas with peers. Therefore, research may need to establish explicit connections between drawings and the methods that they are engaged in during the teaching and learning process.

2.7 CONCLUSION

This chapter has drawn together constructs that are pertinent to teaching and learning with diagrams under the theory of multiple representations, the discussion of a number of significant constructs have been reviewed in attempting to answer the research questions.

In section 1 of the chapter, the researcher has portrayed how scientists reasoned and developed theories and strategies on metacognitive learning. Gilbert (2007) suggested that metacognitive teaching and learning can be best discussed in respect of a person with metavisual capability that includes a range of knowledge and skills in dealing with various modes/levels of representations.

Section 2 discussed the explanatory strengths of instructional representations in conveying meaning between the concrete referent and its sign. The intellectual demand of interpreting representation, have been classified by theorists differently as external and internal (e.g., Zhang, 1997) or as descriptive and depictive (e.g., Schnotz & Bannert, 2003). Even to make sense of one single scientific concept, learners need to move fluently between different levels of representation such as macroscopic, sub-microscopic and symbolic levels (Johnstone, 2000; Treagust & Chittleborough, 2001). No matter in which way representations aid the formation of meaningful learning of a certain science concept, analogical transfer Gilbert (2008)

emphasizes the bridging effects of representations in helping learners build connections between different modes of visualizations.

Section 3 examined specific difficulties and challenges for teaching and learning secondary biology. In this section, students' misconceptions have been categorized based on the representational levels to which particular biological content have been assigned. The difficulties lie not only in interpreting different types of illustrations, but also in switching and integrating learners' understanding across various levels of mental models.

Section 4 aimed at specifying the instructional functions of diagrams in teaching biology. Among all the static visual displays used in instruction, diagrams have an important role to play in demonstrating a wide range of information either abstract or concrete (Pozzer & Roth, 2003). Though a variety of definitions of the term diagram have been suggested, Hegarty et al. first categorized the diagrams used in science education into three types: *ionic*, *schematic*, and *charts and graphs*. Novick further supported this categorization and traced its usage in learning to a number of biological topics such as meiosis and evolution. Furthermore, research on learning with visualization has shown that the use of multiple representations in various modalities and combinations provides unique benefits in learning complex scientific concepts. The review has also brought together the discussions on the connectedness of text and visual medium, because both of them constitute a key component in the multimedia-based instruction.

Section 5 described the theoretical framework for analysing and interpreting data to investigate how the biology learning process implies how and why constraining, constructing and complementary functions occur between diagrams and texts.

CHAPTER 3

METHODOLOGY AND METHODS

3.0 CHAPTER OUTLINE

This chapter discusses the research methodology and the general research methods which have been adopted for this doctoral research. Methodology is the congregation of methods and deals with the philosophical assumptions undertaken within the research process, while a method is a specific technique for data collection underlying those philosophical assumptions. Different research methods were used because the school and classroom contexts in the research varied from one to another.

The chapter presents a discussion of the research paradigm, theoretical orientation, and the research design of the study. Alongside the methodology, different research methods were implemented to respond to the specific research questions. An outline of the research approach is presented in Table 3.1, and the terms included in the table are used to structure this chapter.

3.1 INTRODUCTION

In differentiating between the meaning of methodology and methods, the qualitative research tradition looks at methodology as a way of thinking about and studying social reality whereas methods are a set of procedures and techniques for gathering and analysing data in that reality (Strauss & Corbin, 1998). As the research questions varied in this research, more specific methods are used in different phases of the study. Given the complexity of classroom teaching and learning biology, both qualitative methods (e.g., analysis non-numerical data from interviews, observations field notes and other documents) and quantitative methods (e.g., analysis of questionnaire and content analysis of textbooks) were combined in order to gain a meaningful interpretation of the data. Therefore, appropriate research methods have to align with the paradigm so that they fit the purpose of the inquiry.

Table 3.1: An Outline of the Research Approach Taken in This Study

Aspects of the Research Process	Approach taken in this study
Research paradigm	Constructivism
Theoretical orientation	Mixed methods
Research design	Grounded theory
Methods of data collection	Observations Questionnaires Interviews
Data interpretation	Analysis of field-notes Quantitative analysis Qualitative analysis
Validity & Reliability	Triangulation Adequate sample size
Ethical issues	Informed consent Confidentiality

3.2 RESEARCH PARADIGM

A paradigm is a comprehensive belief system, world view, or framework that guides research and practice in a field (Willis, 2007). All research has a basic set of underlying beliefs and assumptions in relation to ontology, epistemology and methodology. Ontology deals with questions concerning what entities exist and how such entities can be grouped within a hierarchy according to similarities and differences; epistemology refers to ways of knowing, being concerned with what people know about reality and how one can know it, Methodology refers to the big picture when conducting research, including the research design, data collection, analysis and interpretation.

Constructivism underpins the paradigm within which this research was developed. Constructivists believe that knowledge is a construction about which there is relative knowledge amongst those qualified or competent to interpret the data (Guba & Lincoln, 1994). Constructivist learning is depicted to have occurred when new knowledge has been successfully integrated on the basis of the pre-existing cognitive structures through the active engagement of the learner. Humans invent concepts,

models, and schemes so as to make sense of experience and, furthermore “to continually test and modify these constructions in the light of new experience” (Schwandt, 1994, p. 126). The aim of constructivist inquiry is to understand and reconstruct those constructions of knowledge that people initially hold as distinct from the positivist paradigm that insists the essence of enquiry should be explanation, prediction and control of the physical or human phenomena. The constructivist view of epistemology believes that human beings find or discover knowledge as much as construct or make it (Guba & Lincoln, 1994).

The purpose of this research is to make sense of students’ conceptions when they are learning biology with diagrams. The aim is that through the research processes, the researcher will become informed and competent enough to interpret the student and classroom data in order to generate knowledge about students’ learning processes. To construct a holistic picture of the instructional use of diagrams in supporting students’ conceptual learning, it is necessary and beneficial to consider a learning situation from differing theoretical perspectives of conceptual change, including ontological, epistemological and affective dimensions. This purpose fits within the constructivist paradigm and guides and informs choices made in the methods of inquiry and methods of analysis of the research. There also is an expectation that the preliminary constructions made as a result of this stage of research will be continually tested and pave the way for the exploration of other research questions. The epistemology of the study is, therefore, consistent with the constructivist paradigm.

3.3 THEORETICAL ORIENTATION

A mixture of both quantitative and qualitative research approaches allows the researcher to explore research questions in classroom settings that cannot be answered solely by either qualitative or quantitative designs (Creswell, 1994). The quantitative methods may be more suitable to behavioural or descriptive components of research questions of the study; while qualitative methods explore phenomena in their natural settings and use multi-methods to interpret, understand, explain and bring meaning to them.

A mixture methods research design is a procedure for collecting, analysing, and combining the use of both quantitative and qualitative data in a single study to

understand a research problem. With respect to this study, a mixed methods approach (Creswell, Shope, Plano Clark, & Green, 2006) may be of benefit for the following reasons:

- Qualitative methods such as observation or interviews allow the researcher to develop a holistic picture of the research questions.
- Quantitative analysis may complement the findings of qualitative methods by indicating the extent of existence within the subject population. Thus quantitative analysis might be used to confirm or disconfirm any apparently significant data that emerge from the study.

3.4 RESEARCH DESIGN

Research can be described as being deductive or inductive with regard to theory. A grounded theory design is a systematic, qualitative procedure used to generate a theory that explains a process or interaction about a topic at a broad conceptual level. Therefore, grounded theory is a kind of inductive approach to research in which the theory is grounded in or emerges from the data (Patton, 1990). Patton (1990, p. 67) also claimed that “grounded theory depends on methods that take the researcher into and close to the real world so that results and findings are grounded in the empirical world”. Therefore, grounded theorists need to stress flexible strategies, emphasize the meaning that participants ascribe to situations, and acknowledge the roles of the researcher and the individuals being researched.

3.4.1 GROUNDED THEORY

Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed (Strauss & Corbin, 1994, p. 273). Data are collected in multiple stages; emergent themes are identified, interpreted, compared and refined. This process creates a funnel of information from which constructs and theories are developed. These theories are then tested with various sampling groups to examine their strength of the similarities and differences of the theoretical constructs. This form of study does not start with a hypothesis. Instead relationships are established and a working hypothesis is formed after collecting the initial data

which is then checked against further data. The systematic, structured approach to data collection involved in grounded theory enables it to be descriptive and also have explanatory power.

Grounded theory stresses the importance of context in which people function, and the roles they adopt in an interaction. Holloway (1997) claimed that researchers use grounded theory to investigate interactions, behaviours and experiences as well as individual perceptions and thoughts on them. The main aim of ground theory is to generate theory from data, the existing theories can be modified and extended by this approach (Holloway, 1997). Grounded theory needs researchers to start with an area of interest, collect data and allow the relevant ideas to develop. In general, grounded theory analysis proceeds in three steps (Punch, 2005). Firstly, to find conceptual categories in the data; secondly, to find relationships between these categories; and lastly, to conceptualize and account for these findings at a higher level of abstraction. Accordingly, this study followed those three procedures sequentially that took place from generating conceptual categories, in-depth explaining variation of the data that led to theory building.

Phase 1: Investigating the use of diagrams that students are exposed to when learning secondary biology concepts.

A content analysis was conducted with the aim of investigating the different diagram types that students are dealing with in their everyday biology learning. The aim of content analysis is to check the availability of various types of illustrations used in explaining biological concepts. In addition to that, the distributional features of diagrams were explored through the examination of a number of teaching materials, such as textbooks and student workbooks. Nine textbooks were closely examined for the presence of diagrams. Data collection involved extensive searches of student textbooks and teacher resource materials used in Western Australian senior high schools. The textbooks used had been identified by state syllabus organizations as current in Australian senior secondary science and biology education and were used in the school where the research took place. The process of content analysis can be briefly divided into three steps: (1) Coding the diagrams in the nine textbooks. A list of those textbooks examined is found in Appendix 1. (2) Cross-checking the results.

The numbers of all diagrammatic types in each textbook and chapter have been crosschecked several times by the researcher himself together with another academic faculty member. Before that, uniformity on the criterion of the diagram classification was achieved to determine which diagram type does a single illustration belong to. (3) Conducting the quantitative data analysis. Descriptive statistics were conducted in the analysis of the quantitative data to enable the interpretation of any trends that exist between different textbook types related to the lower and upper secondary science and biology textbooks.

Phase 2: Observing teachers' instructional use of diagrams in helping students make sense of particular biological content such as genetics and cellular respiration.

Of particular interest to the researcher were the role of diagram-inclusive instruction and the actual teaching process with diagrams engaged in the everyday secondary biology classroom teaching. Consequently, in keeping with the qualitative approach for research into teachers' and students' use of diagrams, an interpretive design (Erickson, 1986) was used to address this interest. Erickson (1986) suggested that in qualitative analysis, one researcher wants to discover by means of analytic induction, which includes generating a few general assertions and sub-assertions - pattern statements with a wide enough corpus of data connected. The credibility and dependability of interpretive research are affected by access to the school and classes, combined with the researcher's credibility (Goetz & LeCompte, 1984). Through the research conducted into the use of diagrams in textbooks, the researcher was familiar with the scientific diagrams used in teaching, the biology content and had developed skills in the recognition and classification of the diagrams as they were presented. The researcher observed different biology teachers' teaching in a local public senior high school for several semesters. A total of 92 lessons from five biology teachers were observed and teachers' instructional methods of diagrammatic usage were analysed to determine how diagrams are incorporated in everyday biology teaching. The qualitative data collected in this study included field notes, teachers' teaching materials and audio tapes of lessons during teachers' instruction. The author also discussed the findings with his supervisor and other colleagues.

Phase 3: To investigate students' perceptions toward biology teachers' instructional use of diagrams.

Since diagrams are widely used in textbooks, biology classrooms, different diagrams have their own advantages and limitations in guiding learning. Students therefore may encounter difficulties in interpreting diagrams or finding the relations between the diagrams and the concepts they represent. In this stage, an instrument was developed for identifying students' perceptions regarding instructional use of diagrams in their biology class. The development of the instrument for assessing students' perceptions of teachers' instructional usage required several stages:

- Identifying and defining the salient characteristics of teaching approaches in the multiple representational learning environments.
- Referring to and adapting previously validated instruments to determine if the scales identified hold up when the focus is limited to teaching biology with diagrams (Examples of original scales and items are shown in Table 3.2).
- Discussing the items with teachers to ensure the suitability and accuracy of the questionnaire as a whole.
- Revising the questionnaire according to the feedback.
- Administering the questionnaire and conducting the analysis.

By analysing the results from administration of the questionnaire, teachers can examine how those factors are employed in the instructional use of diagrams in the biology classroom.

Table 3.2 Example of Original Scales and Items

Scales	Example items
Instructional	1. My teacher's teaching methods keep me interested in science.
Repertoire	2. My teacher provides opportunities for me to express my point of view. 7. My teacher uses a variety of diagrams when we study different biology topics.
Representational	9. My teacher uses familiar examples to explain scientific concepts.
Repertoire	11. My teacher uses demonstrations to show science concepts. 13. My teacher uses stories to explain science ideas.
Subject Matter	16. My teacher knows the content (s)he is teaching.
Knowledge	19. My teacher knows how science is related to technology. 20. My teacher knows the history behind science discoveries.
Knowledge of	22. My teacher's tests evaluate my understanding of a topic.
Students'	26. My teacher assesses the extent to which I understand the topic.
Understanding	27. My teacher uses tests to check that I understand what I have learned.

Phase 4: To explore how diagrams correlate with textual representations in helping students developing their understanding of biological concepts?

This stage of the research involved searching for consistencies between the data collected in stages 1 and 2 and the various functions of multiple representations as identified in the review of literature (e.g. Ainsworth, 1999). By relating to the theoretical framework and previous research findings, it is intended that this stage may reveal how the three different cognitive functions exist between students' interpretation of diagrams together with text. Since representational modes may be related to each other in conveying meaning, the research of this stage was intended to describe the cognitive processes of individuals' interpretation of biology concepts elaborated through the interplay of diagram and text. In particular, the researcher developed an interview protocol (see Appendix 3), in which a number of biological concepts are illustrated with different types of diagrams and written text. The interviewing procedure was designed to elicit students' interpretation from two sources - diagram and text, respectively - and then to compare and analyse how the information relates to each other. In this regard, the qualitative data were examined to investigate the functional roles of diagrams and text engaged in students' conceptual learning of biological concepts.

As mentioned above, the methodology and the associated methods used in the data collection are from different sources to enrich the data analysis and interpretation. The data collection methods, data sources, analyses and interpretation methods for the four research phases are mapped in Table 3.3. Within grounded theory the research begins with a research situation, the researcher gradually understands what is happening there and manages further data collection as the study proceeds. Charmaz (2000) claimed that grounded theory fits within the constructivist paradigm because it allows theory to emerge as connections between interpretations of data accumulate. Once the data collection proceeds, the links between theoretical propositions occur in different research phases that help to discover the theory implicit in the data.

Table 3.3: Mapping the Research Methods to Research Questions

Research Objectives	Research Questions	Data Collection Method (V=verbal data; N=numerical data)				Source (T for teacher; S for students)	Methodological Framework in Data Analysis
		Observations	Content analysis	Questionnaire	Interview		
Phase One	RQ1 What kind of diagrams are students exposed to when learning science and biology in senior high school?		N			S	Interpretive research
	RQ2 How are diagrams distributed in textbooks?		N			S	Interpretive research
	RQ3 What are the development tendencies of the diagrammatic usage in the textbooks?		N			S	Interpretive research
Phase Two	RQ4 How do teachers choose to use different types of diagrams when teaching secondary biology?	V				T & S	Discourse analysis, verbal analysis
Phase Three	RQ5 What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?			N		S	Interpretive research
	RQ6 What are students' perceptions of teachers' instructional strategies with diagrams?			N		S	Interpretive research
Phase Four	RQ7 What roles do diagrams and text play when learners relate both representations to understand biological concepts?				V	S	Discourse analysis, verbal analysis

3.5 INTERPRETIVE RESEARCH

Interpretive research attempts to understand the meaning perspectives of the participants, such as in the search for patterns of meaning-in-action and for building up new theories (Patton, 1980). Interpretive research describes people acting in events and provides the reader with a depiction in enough detail to show that the author's conclusions make sense. In this study, quantitative data (questionnaires) and qualitative data (interviews and other verbal data) were analysed using interpretive research methods. The quantitative methodologies and methods in this study referred to descriptive statistics following a systematic content analysis of diagrams in textbooks. Qualitative methodologies and methods generally follow the qualitative research inquiry that explores the profound understanding of the world through conversation and observation in natural settings rather than through experimental manipulation under artificial conditions.

3.6 METHODS OF DATA COLLECTION

3.6.1 QUANTITATIVE METHODS

The quantitative data primarily consisted of the results of a textbook content analysis and the questionnaire.

3.6.1.1 Content Analysis of Textbooks

Content analysis in this research entails a systematic reading and categorizing of a body of diagrams, drawings, photos and text from a number of secondary school textbooks. The three types of biological diagrams noted by Novick (2006) have been found and employed in all levels of secondary biology textbooks. Using this diagram classification framework, the researcher's intention was to examine closely the nature and extent of diagram use in biology textbooks used by Australian high school students. All the diagrams were coded according to the typology proposed by Novick (2006). Accordingly, a great amount of empirical data was generated by scrutinizing of each textbook that provided the needed scientific groundwork for the research of the next stage. Content analysis not only provided evidence for answering the research questions in research objective one, but also paved the way for the further

exploration of the roles that diagrams may have in students' understanding of biology concepts. For the purpose of the study, the following specific research questions were addressed:

To investigate the kind of diagrams used in biology teaching and learning.

1. What kinds of diagrams are students exposed to when learning biology in senior high school?
 - 1.1 How many diagrams are included in each textbook?
 - 1.2 How frequently are diagrams to be included?
2. How are diagrams distributed in textbooks?
 - 2.1 The frequency of each type of diagram occurred in each chapter/book?
3. What are the development trends of the diagrammatic usage in the textbooks?

Nine biology textbooks were closely examined for the presence of diagrams (see Appendix 1). Each diagram was analysed in respect of the criterion of the diagram classification framework proposed by Novick (2006). My supervisor and a visiting Canadian scholar acted as independent examiners who cross-checked the results of content analysis so as to improve the inter-rater reliability of the study. First of all, an agreement was reached about the criterion used in classifying diagrams, such as particular features were defined so that the specific diagrammatic type could be determined; second, the results of content analysis were cross checked by the two scholars; any diagrams in dispute were examined once again. The accuracy of the results as shown in table 4.1 was ensured thereafter.

3.6.1.2 Questionnaire

The decision to use a questionnaire is often motivated by a need to collect routine data from a large number of respondents who may be in one or several locations (Arsenault & Anderson, 1998). A questionnaire is one of the quantitative instruments that are easy, quick and convenient to administer but their value depends on the quality of the items. The reason for administering a questionnaire is so that the researcher could gather reasonably valid quantitative data in a simple, timely and

cost efficient manner. In this research, a self-completion diagnostic questionnaire was designed and administered to senior high school students to help identify their perceptions of the diagrammatical learning environment. The questionnaire contained statements on evaluating students' perceptions of their teachers' diagrammatic usage in the everyday biology classroom.

The reliabilities of each scale in the instrument were tested and proved to be reliable through statistical analysis. An instrument *Students' Perceptions on Biology Teachers' Use of Diagrams* was designed and administered to students in the format of pen and paper. Throughout the research process, the instrument was modified based on the outcomes of classroom observations and the feedback of biology teachers. The modification of the instrument at this stage ensured the items addressed the key components of diagrammatic teaching.

To measure students' perceptions regarding teachers' instructional use of diagrams in the process of teaching and learning biology concepts, the following two specific research questions were addressed.

5. What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?
6. What are students' perceptions of teachers' instructional strategies with diagrams?

The development process of the instrument included several steps: (1) Identifying the salient characteristics of biology teachers' teaching practice; (2) Composing the items for each scale; (3) Seeking biology teachers' opinions and revising the items; (4) Administering the questionnaire. A total number of 214 students from Grade 9 to grade 10 answered this questionnaire. Four biology teachers' classes were assessed according to students' responses marked on the five-level Likert scale. The study examined the centrality of teacher's role in creating an effective diagrammatic learning environment that promotes students' cognitive and affective learning achievements. The results may also reveal students' perceptions on teachers' instructional usage when diagrams were employed.

3.6.2 QUALITATIVE METHODS

The qualitative data primarily consisted of the results of the participant researcher's observations, field notes and students' worksheets, and interview data.

3.6.2.1 Classroom Observations

The classroom observations of this study were conducted in different grades of biology classes at one public senior high school in Western Australia. During classroom observations, the researcher assumed the role of an "observer as participant" (Merriam, 1998a, p. 101), where the researcher did not engage in the regular instructional activities of the biology classes. Throughout the investigation, the researcher did not interfere in the teaching so that the control of the classroom remained with the teacher. Field notes were recorded by the researcher and classroom activities specifically of interest to the research were audio-taped.

The classes were observed to different degrees depending on the amount of time that teachers were prepared to have the researcher in their classrooms, the availability of classroom time, and the availability of students for further data collection. This meant that a variety of biological topics taught by different biology teachers and students from different grades were observed by the research.

The observations allowed the researcher to observe teachers' and students' actions in their natural field setting. As Merriam (1998b) pointed out, not only can observations provide a researcher with knowledge of the specific content, the researcher can also observe things that the observed would not have been willing to talk about, i.e., specific instances could serve as references for subsequent interviews. During the observations, teachers' methods of teaching a biology concept with diagrams were recorded and analysed so as to find out how different types of diagrams were used in the secondary biology teaching.

The following research question was addressed:

4. How do teachers choose to use different types of diagrams when teaching secondary biology?

Table 3.4 Summary Table of Lessons Observed

Teachers		Grade	# of lessons observed	Biological Contents Observed
K		Y 11, Y12	40	Sensory system, Photosynthesis
D		Y 11, Y12	15	Genetics, respiration
C		Y9, Y10	10	Food chains
B		Y9, Y10	15	Blood Circulation
S		Y9	12	Cell structure,
Total teachers	5	Biology Y9 – Y12	92	

As shown in Table 3.4, in total 92 biology classes from five teachers were observed, and a great number of field notes, teachers' handouts and student worksheets were collected and examined. The observations were conducted on a regular basis, about three or four times every week. The researcher spent more than one semester (seven months) in the school observing most of the biology teachers' lessons. For every lesson observed, the field notes were jotted down so that could be collated with teachers' handouts. To ensure the data collection procedures were reliable, these notes and observations were routinely discussed with the researcher's supervisor and another researcher who had also made observations in the same biology teachers' classrooms.

3.6.2.2 Interviews

The student interviews aim at probing students' conceptual understanding of diagrams in terms of whether or not they complement, constrain and or help construct the other mode of representation, namely, text. The interviews were semi-structured with a set of questions and issues to be explored. In order to probe the post-instruction understanding of a number of biological diagrams, particularly the 63 biological concepts, the content of the student interviews took the form of "interview about concepts" (Carr, 1996). Consequently, the semi-structured

interview was considered to be appropriate for the data collection in this research because a certain level of structure was desirable for the interviews in order to give direction to the data collection and facilitate data analysis with adequate reliability. The interview protocols used in the study allowed the interviewer to probe and expand the interviewees' responses. The total number of students interviewed across years is shown in Table 3.5.

The interviewing process can be summarized as: (1) To investigate interview participants' understanding of one representation – diagram / text; (2) To retrieve the interpretation of the other representation – text / diagram; (3) To compare the information from both representations and analyse how they relate to each other. The questions and wording were predetermined with the aim of exploring students' interpretation of diagrams and text of topics that they had already studied in the class several months prior to the interviews. Interviewed participants were audio-recorded and fully transcribed. According to Chi (1997), verbal analysis is a method for quantifying the subjective or qualitative coding of the contents of verbal utterances whereby the researcher tabulates, counts and draws relations between the occurrences of different kinds of utterances to reduce the subjectiveness of qualitative coding (Guba & Lincoln, 1989). Unlike protocol analysis, verbal analysis focuses on capturing student's knowledge and the cognitive processes. The interviewing data were vital in probing students' conceptual processes while learning biology domain knowledge with diagrams.

Table 3.5 Summary of Interview Participants

Grade	Year 9	Year 10	Year 11	Year 12	SUM
Number of students	Nil	9	2	Nil	11

Participation was voluntary and each of the 11 participants explained their understanding process by relating both types of representations. In order to protect privacy, the 11 students are referred to in this thesis later as Student 1, student 2,... and student 11, that is, the sequence of attending the interview. The number attached

to each student has nothing to do with his / her years of schooling or academic achievement, but only served as an identity for the convenience of data analysis.

The fourth research phase focused on the Research Question 7: What roles do diagrams and text play when learners relate both representations to understand biological concepts? The researcher investigated how the two representations relate to each other in individual's learning of biological content knowledge. Students' interpretations from the two representations were analysed in regard to the theoretical framework, and the interview data provided opportunities for exploring the effects that multiple types of representations such as diagrammatic and textual representations on the biological learning.

3.7 ANALYSIS AND INTERPRETATION OF DATA

The outlined methodology and its associated methods in collecting data were conducted from multiple sources using mixed research methods (Creswell, 1994). The mixed methods require suitable strategies in data analysis and interpretation. The section provides a summary of these methods by mapping them according to the nature of the data collected.

3.7.1 QUANTITATIVE DATA

Quantitative research involves measurements, usually of a number of variables, across a sample (Punch, 2005). The Statistical Package for Social Scientists (SPSS) version 18 (SPSS, 2011) was used to analyse the quantitative data. Descriptive statistics showing frequencies, means, standard deviations and are commonly presented. The reliability of the instrument was ascertained through Cronbach alpha reliability.

3.7.2 QUALITATIVE DATA

In managing and analysing the non-numerical or verbal data, both manual analysis and computer-based analysis (*Nvivo* software) were used. The software helped the researcher organize the non-numerical documents for the convenience of search,

retrieval and comparison of data coded under particular categories. The qualitative data were coded in terms of relevant aspects of students' understanding and activity (Silverman, 2000). Categories were created to correspond to the analysis of the data in light of the research questions. As categories were created and coding continued, the robustness of each category was assessed, resulting in continual adjustment and refinement of the categories. This process continued throughout the coding process. After the coding of all documents was complete for a particular question or concept, the coded data for each category was inspected and the frequency and accuracy of the coding assessed. A visiting scholar acted as an independent researcher to crosscheck the coded categories of textbook content analysis so as to verify the accuracy of analysing practice. Descriptive statistics were conducted in order to provide first-hand data on exploring how diagrams are distributed in biology books.

3.8 VALIDITY AND RELIABILITY OF THE DATA

3.8.1 VALIDITY OF THE DATA

Quantitative and qualitative data collected in the studies served as a form of methodological triangulation in order to improve the validity and quality of data (Mathison, 1988). The validity of particular quantitative instruments involved the large-scale administration of the survey and encouraging respondents to provide honest and accurate responses. The combination of multiple data sources described as triangulation helped to provide validity to the data by providing corroborating results for a holistic view of learning biology with diagrams (Mathison, 1988). The interviews and analysis required vigilant attention to the researcher's personal biases, for example guarding against pre-conceived ideas or leading the participant.

3.8.2 RELIABILITY OF THE DATA

Cohen et al. (2007) suggest that qualitative data can be treated like quantitative data by considering the stability of observations, parallel forms and inter-rater reliability of the data. Supporting evidence was collected to build up new ideas. Based on previous findings consistent with a constructivist scenario, the initial research stage of the study involved a great amount of observations, followed by collecting

quantitative data by conducting the questionnaires with a wide range of responses. Considering the researcher's opinions and beliefs may introduce a bias into the research, the strategy of employing adequate sample size was also adopted for the interview data collection. The researcher was keen to have an adequate sample size to encourage as many as students and to participate.

3.8.3 TRIANGULATION

Triangulation is typically perceived as a strategy for improving the validity of research or evaluation findings. The validity of qualitative approaches to research can be threatened because they can be subjective and present a biased view of the real situation. Merriam (1998b) suggested the validity of research findings is enhanced by the use of triangulation so that many sources of data and data collection techniques are utilized and the analysis is carried out from different perspectives. The comprehensive approach to triangulation of data collection and interpretation levels for each of the research questions is outlined in the Table 3.6.

Table 3.6: The System of Triangulation in the Research Design at the Data Collection and Interpretation Levels

	Phase 1	Phase 2	Phase 3	Phase 4
Research Questions	1, 2, 3	4	5, 6	7
Method of Data collection	Content analysis of textbooks	Classroom Observations	Questionnaire	Interviews
Chapters	Chapter 4	Chapter 5	Chapter 6	Chapter 7
Triangulation strategies	Crosschecked by other independent researchers	One schools/five biology teachers' classes been observed Observations also conducted by supervisor and another scholar	215 participant students from grades 9 and 10 Questionnaire was examined by other science educators and school teachers	11 students participated Results were crosschecked by supervisor and another science education researcher

3.9 ETHICAL ISSUES

The researcher gave full consideration to all participants and their learning environments. The data collected for this project have not been of a highly sensitive nature, politically, socially or physically. Regardless of this, it is important to sustain a notion of respect for every individual involved and to obtain students' cooperation and consent to use the information obtained in this research. While endeavouring to achieve the objectives of the research, the researcher attempted to conduct the research in a manner that did not interfere or conflict with any participant. The students were mostly positive and interested in the project, keen to contribute their parts.

3.9.1 CONSENT

The research was conducted on the basis of teachers and students volunteering to participate in the study. The first ethical approval was sought from the Curtin Human Research Ethics committee as soon as the Curtin Candidacy Proposal was approved. Later, a detailed proposed data collection methods and ethical application was submitted to the Department of Education and Training, Government of Western Australia. The researcher could therefore conduct research at Department of Education sites and invite site managers for their participation and cooperation in the project. In addition, permission also was obtained from the school principals, teachers, parents or guardians and students of participating schools to complete questionnaires and interviews. With classroom observations, the research was allowed to observe a group of biology teachers' teaching through verbal requests or online written requests. Those teachers were willing to accommodate the researcher in their classes and to observe their teaching with diagrams. For administering the questionnaires, permission was obtained from the teachers and principals of the participating schools for the students to complete the anonymous questionnaires. With the interviews, students were advised to discuss their involvement in the research with their parents. Parental and teacher permission slips were read and signed before the research began.

3.9.2 CONFIDENTIALITY

The identification of any participants was protected. Where a name is used, it is a pseudonym. A coding system was used to document the participant and the data source. All data were identified with a series of letters and digits: the first capital letter refers to the initial letter of the first name of participant; the second digit refers to the grade of students; and then followed by 3-4 letters in lowercase that show the biology topic being taught; the remaining digits refer to the date that the information has been collected. For example:

(K10 resp 4.9.10) Teacher Ken, Year 10 class, respiration, September 4th, 2010.

Moreover, any electronic data collected during the study was stored on a computer protected by passwords. Any paper format collected was stored in locked filing cabinet at Science and Math Education Centre at Curtin University. Only the thesis committee and the researcher have access to the data. All electronic and paper format data produced will be stored in a safe and secure location for a period of 5 years after publication of the thesis.

CHAPTER 4

CONTENT ANALYSIS OF TEXTBOOKS

4.0 CHAPTER OUTLINE

This chapter presents a content analysis of textbooks used to answer the relevant research questions. While the nature of the content area influenced the frequency of diagrams, the included diagrams were often the variants of those in different grades of science textbooks. The first section of the chapter provides the results of the content analysis on the different types of diagrams in each textbooks; the second section reveals the distribution differences of diagrams in the lower secondary school science textbooks, upper secondary biology textbooks, and biology workbooks. In the last section, the trends of diagrammatic usage across years are reported.

4.1 INTRODUCTION

An earlier study of biology textbooks found that there are on average 0.55-0.78 photographs, 0.19-0.22 diagrams, and 0.18-0.23 naturalistic drawings per page (Pozzer & Roth, 2003). The interpretation of diagrams may be a demanding task for students. Pozzer and Roth (2003) reported that students may have difficulties when interpreting illustrations in biology textbooks; for example, multiple objects are always shown in one image, multiple related images are contained in one figure, and the colour coding, arrows, or numbering are used without explanation. Recently, Cromley and her colleagues (2010) followed Roth et al.'s ontology of graphs and further investigated some particular visual representations such as naturalistic drawings, line diagrams and flow charts in biology and geoscience textbooks. These authors also argued that different domain knowledge and conventional rules used in the diagrams could have an impact on students' learning.

Despite previous studies arguing that diagrams are ubiquitous in science textbooks and journal articles, few research studies have been conducted to analyze the content and the distribution of different types of diagrams in secondary science textbooks. Since diagrams are frequently used in secondary biology teaching and learning

materials, then it could be expected that there be uniformity among their frequency of use.

The first objective of the research aims to examine the nature and extent of the use of diagrams in biology textbooks and workbooks used by secondary students in Western Australia. In this section, analysis was made of the frequency with which different types of diagrams occurred in different content of biology textbooks. Novick (2006) proposed three types of diagrams (iconic, schematic, or charts & graphs) that are used in science teaching; their modes of operation vary noticeably between applications in science teaching. This study is to find out how diagrams are used in the teaching context, especially their distribution in secondary textbooks?

Data from a content analysis of textbooks were used to respond to the two research questions that underpin objective 1. The specific research questions were addressed:

Research Question 1: What kind of diagrams are students exposed to when learning science and biology in senior high school?

Research Question 2: How are those diagrams distributed in textbooks?

Research Question 3: What are the development trends of the diagrammatic usage in the textbooks?

4.2 CONTENT ANALYSIS OF TEXTBOOKS

Based on the three types of diagrams proposed by Novick (2006), the classification of scientific diagrams contained in a range of science textbooks and biology textbooks used in Western Australian secondary high schools were examined related to their portrayal of biological concepts. A total of nine books (seven textbooks and two student workbooks) are currently available for use by senior high school students in Western Australia. *Fundamentals of science book 1-4* are textbooks comprise of many science subjects for junior years students, whereas the contents not only biology but also chemistry, physics and natural science are all included in these books. The researcher included these books into the study of content analysis otherwise diagrams used in the biology teaching could be missed. Other textbooks and workbooks are completely used in the biological teaching and learning.

Therefore the diagrams contained in all those textbooks were counted and classified, and the percentages of each type of diagram were calculated. Descriptive statistics were conducted in order to provide first-hand data on exploring how diagrams are used in biology books.

My supervisor and another scholar acted as independent examiners who cross checked the results of content analysis so as to improve the inter-rater reliability of the study. The inter-rater reliability between the three raters was 0.89 so that the accuracy of the results in Table 4.1 was ensured thereafter.

4.2.1 PREVALENCE OF DIAGRAMS

Research Question 1: What kind of diagrams are students exposed to when learning science and biology in senior high school?

Content analysis was conducted to examine the inclusion of images in textual materials. Descriptive statistics for each textbook, including the title of the textbook, the total number of pages in the book, as well as the number and the proportion of every diagram type are presented in Table 4.1. The three distinct types of diagrams are found in all the textbooks. However, several features are evident:

(1) Secondary biology textbooks contain a tremendous amount of diagrammatic illustrations. There are 5340 diagrams in a total number of 3494 pages of textbooks. Though there is a slight difference in the mean of the total number of diagrams per page, varying from 0.8 (Human biology 2) to 3.16 (Student Resource and Activity Manual 1), there are on average 1.5 diagrams per page used for the explanation of biological content.

(2) The three categories of scientific diagrams (iconic, schematic, charts & graphs) have been identified in every chapter of each of the biology books. In general, the most frequently used diagrammatic type is iconic (69.63% in total diagrammatic usage), whereas schematic diagrams together with charts & graphs account for 24.14% and 6.24%, respectively. Iconic diagrams have been used the most frequently in the book *Student Resource and Activity Manual 1* (83.48% of the total diagrammatic usage); the book *Biology: An Australian perspective* contains the most amount of

schematic diagrams (35.04%); and charts & graphs were found to be the most populous with the textbook authors in *Biology: An Australian perspective* (9.54%), whereas the lowest figure of 2.8% was seen in the book *Fundamentals of Science Book 3*.

Table 4.1 Summary of Content Analysis of Lower Secondary School General Science Textbooks and Upper Secondary School Biology Textbooks

Number	Book	Pages	Iconic		Schematic		Charts & Graphs		Total
1	Fundamentals of science Book 1	306	480	80.19%	97	16.26%	21	3.55%	598
			12.86%		7.61%		6.31%		11.19%
2	Fundamentals of science Book 2	306	399	75.18%	115	21.74%	17	3.08%	531
			10.69%		9.03%		5.11%		9.94%
3	Fundamentals of science Book 3	298	250	69.89%	98	27.31%	10	2.80%	358
			6.70%		7.69%		3.00%		6.70%
4	Fundamentals of science Book 4	368	291	58.6%	160	32.32%	45	9.08%	496
			7.80%		12.56%		13.51%		9.29%
5	Human Biology 1	320	148	56.5%	99	37.77%	15	5.73%	262
			3.98%		7.68%		4.50%		4.91%
6	Human Biology 2	398	209	60.1%	121	34.77%	18	5.13%	348
			5.60%		9.50%		5.41%		6.52%
7	Biology: an Australian perspective	718	373	55.42%	236	35.04%	64	9.54%	673
			9.99%		18.53%		19.22%		12.60%
8	Student Resource and Activity Manual 1	394	1041	83.48%	132	10.59%	74	5.93%	1247
			27.8%		10.36%		22.22%		23.36%
9	Student Resource and Activity Manual 2	386	527	63.72%	231	27.94%	69	8.34%	827
			14.12%		18.13%		20.72%		15.49%
		3494	3718	69.63%	1289	24.14%	333	6.24%	5340

4.2.2 DISTRIBUTION DIFFERENCES

Research Question 2: How are diagrams distributed in textbooks?

The content analysis also suggests that there are differences in the distribution of the diagram types not only between textbooks, but also within the specific chapters of each book. The reason for this is that each diagram type has its own unique characteristics in demonstrating a certain type of information, and this also accords with the intended students of different age groups. Therefore, the diagrammatic distribution varies according to the content being taught.

As the different age groups mentioned above, other striking results emerged by grouping all these textbooks broadly into three categories. The reason for analysing the diagrammatic selection in different textbook types is that they have been adopted differently in lower and upper secondary science or biology teaching.

The amount and the majority of the diagram usage in these books varies between lower secondary textbooks and upper level textbooks. In particular, *Fundamentals of Science Book 1 – 4* are lower secondary school textbooks, which provide a combination of general science topics including ecology, natural science, biology, chemistry and physics. *Human Biology Books 1 – 2* and *Biology: An Australian perspective* are upper secondary textbooks with their content completely focused on biological science. *Student Resource and Activity Manuals 1 – 2* are mainly for students' assignment and self-evaluation purposes. The diagrammatic distribution in the three textbook categories are depicted in Figure 4.1.

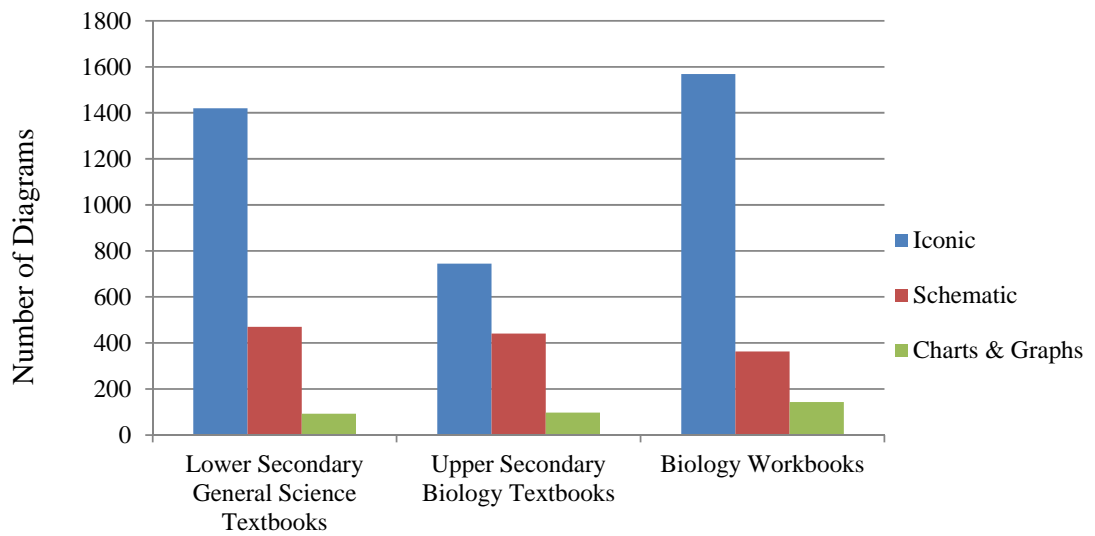


Figure 4.1 Distribution Differences of Textbook Types

Several distribution patterns are evident:

- (1) Though iconic diagrams account for the most diagrammatic usage in every textbook type, upper secondary biology textbooks contain relatively less iconic diagrams than other textbook types (745 vs 1420 in lower secondary general science books and 1568 in biology workbooks). From this finding, therefore, it can be assumed that beginning biology learners may refer to the iconic diagram type more frequently, which typically bears the isomorphic relations to the concrete referent object in its graphic depiction. In other words, learners may depend more on iconic diagrams for visualizing what the biological entities and phenomena look like.
- (2) The largest quantity of charts & graphs can be found in the biology workbooks (143 in all), although the absolute quantity of charts & graphs is not as large as the numbers of iconic and schematic diagrams. The number of charts & graphs adopted by lower secondary general science textbooks and upper secondary biology textbooks are 93 and 97, respectively. It is noteworthy that the charts & graphs category contains highly quantitative information that is drawn in the form of pie charts, line graphs, etc. Consequently, these attributes are incorporated into the general graphic usage by textbooks and therefore these mathematical graphs could be used in assessing students' learning.

(3) Though a relatively similar amount of schematic diagrams have been used in the three textbook types (470 in lower secondary general science textbooks, 441 upper secondary biology textbooks and 363 in biology workbooks), schematic diagram types have different proportions in the total diagrammatic usage of every textbook genre (see Figure 4.2.1, Figure 4.2.2 and Figure 4.2.3). It obvious to note that schematic diagrams are more likely to be used in the upper secondary biology textbooks than lower secondary biology textbooks and biology workbooks (34% vs. 24% and 17%). This may be because schematic diagrams tend to help simplify complex situations by providing a concise depiction of the abstract structure; by relying on this feature, students could interpret those complex concepts in the upper secondary biology textbooks more easily. Therefore, schematic diagrams have the didactic advantages for learners to figure out why and how a complex biological mechanism functions in such a way.

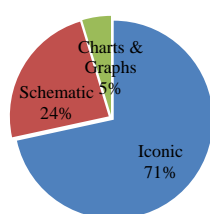


Figure 4.2.1 Percentage of Schematic Diagrams in Lower Secondary General Science Textbooks

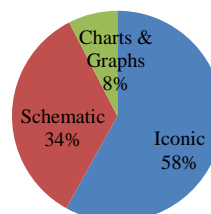


Figure 4.2.2 Percentage of Schematic Diagrams in Upper Secondary Biology Textbooks

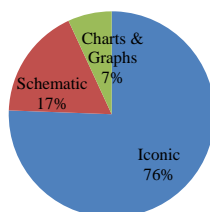


Figure 4.2.3 Percentage of Schematic Diagrams in Biology Workbooks

4.2.3 TRENDS ACROSS TEXTBOOK TYPES

Research Question 3: What are the development trends of the diagrammatic usage in the textbooks?

In addition to the results presented earlier in the chapter that the three textbook types vary in their diagrammatic compositions, this section reports on the developmental trends of diagrammatic usage within each textbook type. As time goes on, students may experience increasing difficulty in learning the content knowledge embedded within the visual representations. This section depicts the conceivable consistencies of the diagram inclusion by the different types of textbooks.

The total number of diagrams contained by lower secondary textbooks (1983) is higher than it in the upper secondary textbooks (1283). In particular, these trends show the changes of different diagram types from lower secondary grade textbooks to upper secondary level textbooks. It thus can be expected that there are some uniformities among their frequency of usage when textbook authors allocate different types of diagrams:

- (1) There is a gradual decline in use of iconic diagrams in the lower secondary general science textbooks, while both schematic and charts & graphs increase slightly. (See Figure 4.3.1 Trends within the lower secondary general science textbooks). *From Fundamentals of Science Book 1 to Book 4*, the percentage of iconic diagram decreased from 80.19% to 58.6%. However, the proportions of both schematic diagrams and charts & graphs peak in Book 4, reaching 32.32% and 9.08%, respectively. It makes an important distinction of diagrammatic usage between the general science textbooks used for lower secondary classes. The higher the student's grade, the less likely the student to be exposed to iconic diagrams in these textbooks.

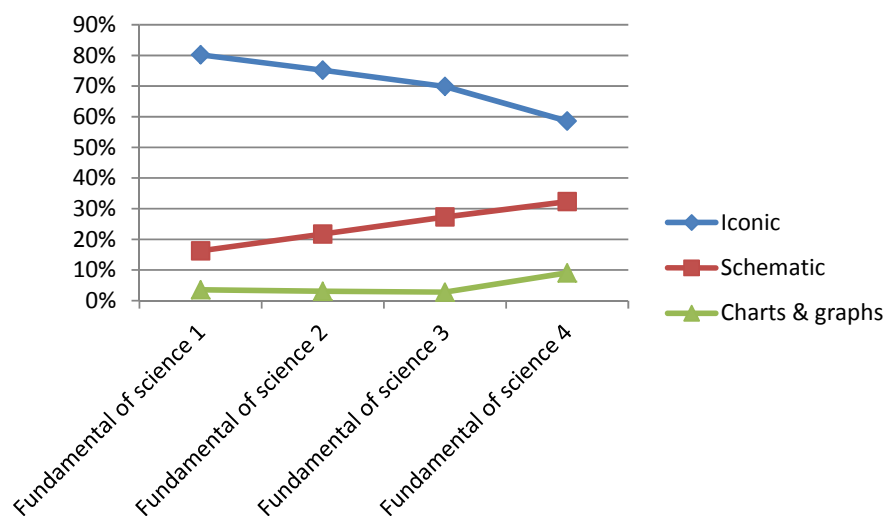


Figure 4.3.1 Trends across the lower secondary general science textbooks

- (2) The trends displayed within the upper secondary human biology textbooks are shown in Figure 4.3.2. That is, the amount of the diagram types remained unchanged. The percentage of iconic usage increased from 56.5% to 60.1%; the percentage of schematic diagrams dropped from 37.77% to 34.77%; and there is slight decrease in the use of charts & graphs, from 5.73% to 5.13%. The results of this investigation show that three types of diagrams possess approximately similar percentage of usage in illustration of secondary human biological concepts.
- (3) The more senior the student, the more likely the student has access to learning biological concepts with schematic diagrams and charts & graphs as shown. In Figure 4.3.2 where indicates the analysis of upper secondary biology textbooks. There is a slight decrease in the use of iconic diagrams, from the percentage of 62.21% in the *Human Biology Book 1* to 55.42% in *Human Biology Book 2*. Meanwhile, the book *Biology: An Australian perspective* has the highest percentages of schematic and charts & graphs usage (35.04% and 9.54%).

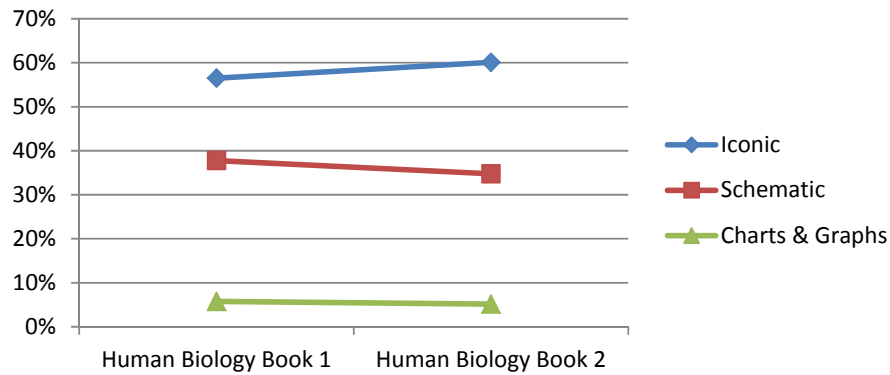


Figure 4.3.2 Developmental trends within the upper secondary biology textbooks

- (4) The patterns for diagrams used in student workbooks are consistent with those in the textbooks, even though workbooks are used mainly for the purpose of students' self-evaluation and served as complementary learning materials to the textbooks. The percentage of iconic diagram drops from 83.48% to 63.72%; Schematic diagrams increased steadily from 10.59% to 27.94%; and there is minor increase of charts & graphs from 5.93% to 8.34%. Details are provided in Figure 4.3.3.

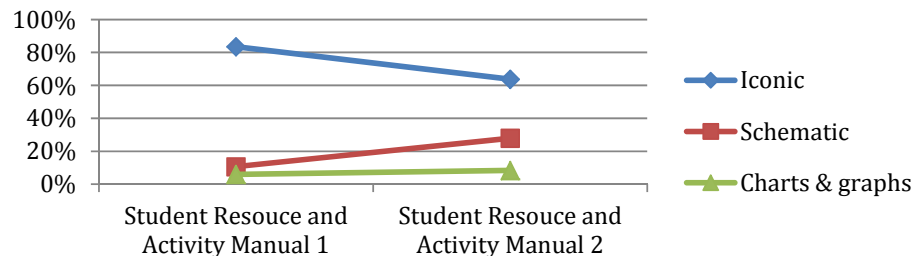


Figure 4.3.3 Developmental trends within the student workbooks

Overall, these trends in the prevalence of the three diagrammatic types in high school science textbooks reflect variations in their perceptions of the likely advantages of different diagrammatic types in teaching various scientific contents. It is evident that textbook authors tend to use more iconic diagrams in the junior secondary year textbooks; however, senior secondary year textbooks appear to include schematic

diagrams and charts & graphs more frequently as the scientific content goes much in-depth as shown in Figure 4.3.4.

	Iconic	Schematic	Charts & graphs
Elementary biology textbooks	↓	↑	↑
Advanced biology textbooks	↑	↓	↓
Student workbooks	↓	↑	↑

Figure 4.3.4 Developmental trends in the three textbook

4.3 SUMMARY

An examination of the nine general science and biology textbooks used by Western Australian senior high school students enabled a response to the first research objective on the use of diagrams, the distribution of diagrams across the textbooks for teaching lower secondary general science and upper secondary biology. The results of the content analysis indicated that a large amount of diagrams are included in the secondary science and biology textbooks used in the classes observed in this research. The diagrams serve as an important teaching technique implemented by textbook authors to present biological content knowledge to the students.

The distribution of diagrams in these textbooks also provided a glimpse of the perspectives of teachers on the use of different diagrams. Each of the nine science textbooks included diagrams which served as a holistic manner in the teaching such as assessment and explanation of content knowledge. In addition, the importance of the classroom teacher in an investigation of diagram use in biology appears paramount. The next section seeks to address that need by observing several teachers teaching with diagrams in the naturalistic setting of the classroom and by analyzing their use of diagrams.

CHAPTER 5

AN INTERPRETIVE EXAMINATION OF SECONDARY TEACHERS' USE OF DIAGRAMS IN BIOLOGY LESSONS

5.0 CHAPTER OUTLINE

This chapter presents data analysis results collected through classroom observations in relation to biology teachers' instructional use of diagrams in everyday biology teaching. In addition to the textbook usage of diagrams stated above, another aspect of how diagrams have been used in biology classroom teaching was investigated to determine the factors related to diagrammatic representation. This section seeks to describe how teachers and students use diagrams presented in the natural setting of the classroom.

Diagrams can be presented to students in a variety of ways. Having examined nine biology textbooks used by Western Australian senior high school students and explored the distribution of diagrams in secondary textbooks, diagrams can also be generated and presented to students by teachers. This chapter seeks to address the research question related to the use of diagrams by biology teachers in a naturalistic setting. In this section, another perspective of viewing the biology classroom use of diagrams was investigated in order to determine instructional methods related to diagrammatic teaching and learning in the natural environment.

5.1 INTRODUCTION

In regard to the use of diagrams in the classroom, this chapter adopted qualitative research methodologies drawing heavily from classroom observations. Data from observing classroom teaching are utilized to respond to the research question that underpins objective two. The specific research question was addressed is:

Research Question 4: How do biology teachers choose to use different types of diagrams when teaching secondary biology?

From a teaching perspective, observation methods were used to describe the diagrams together with the instructional methods used by teachers based on a large

number of biology lessons. The observations allowed the researcher to explore teachers' and students' actions in their natural field setting. As Merriam (1998b) pointed out, not only can observations provide a researcher with knowledge of the specific content, the researcher can also observe things that the observed would not have been willing to talk about, i.e., specific instances could serve as references for subsequent investigations.

During the observations, teachers' methods of teaching a biology concept with diagrams were recorded and analyzed so as to find out how different types of diagrams were used in the secondary biology teaching. The classroom observations of this study were conducted in different grades of biology classes at two senior high schools in Western Australia. A variety of biological topics taught by different biology teachers and students from different grades were observed in the research. The biology topics to be included in this section are: lives in the water, evolution, cellular respiration, blood circulation, neuron, Human Respiratory System, circulatory system, breeding population, and enzyme reaction. The classes were involved in observations to different degrees depending on the amount of time that teachers were prepared to have the researcher in their classrooms, the availability of classroom time, and the availability of students for further data collection. Throughout the investigation the researcher did not interfere in the classroom so that the teaching was completely in the control of the teachers.

This study builds on the following outcomes in an attempt to describe how teachers of biology use diagrams to introduce, explain and evaluate abstract biology concepts. It does not measure the frequency of diagrammatic use, but examines how and why teachers use diagrams when they are teaching specific areas of biology. Of particular interest to the researcher were the process of diagram-inclusive instructional practice and the specific diagrams actually used. An interpretive design (Erickson, 1986) was used to address this interest. As the interpretive research methods allow the researcher to visualize the nature of practices in the classroom room. Field notes were written and classroom activities specifically of interest to the research were audio-taped. Field notes were taken in order to keep a record of the specific details of the interactions between teachers and students that occurred in the diagrammatic teaching and learning circumstances. A total of 120 lessons from five biology teachers were observed; all the teachers were chosen due to recognized good biology

expertise, experience in teaching, and willingness to engage visual media into their teaching. Teachers' instructional use of diagrams will be analyzed in the investigation of how diagrams are incorporated in the everyday biology teaching.

From an analysis of the lessons observed, eight assertions were identified using the methodology described in chapter three. The first two assertions (Assertions 1a and 1b) are concerned with how teachers choose to use iconic diagrams when beginning to teach a biology lesson. The third, fourth, and fifth assertions (Assertion 2a, 2b and 2c) provided evidence for the how teachers choose to explain a biology topic and assess students' learning with iconic and schematic diagrams. The sixth assertion (Assertion 3a) emphasized the analogical features that diagrams have in representing scientific information. The seventh assertion (Assertion 3b) indicates that teachers' analogical usage may rely on their own personal experience. The last assertion (Assertion 4a) shows how diagrams together with other modes of representations such as text were used in organizing the concepts and engendering meaning. All the findings generated by the classroom observations may provide a holistic view on understanding how different types of diagrams were used in the natural biology classroom teaching.

5.2 FINDINGS OF THE OBSERVATIONS - ASSERTION ONE

Assertion 1: Iconic diagrams helped teachers introduce a new biological topic together with the knowledge context to students.

Because of working memory limitations, the first step for comprehending graphics always involves selecting relevant features from modes of representations for further processing (Mayer & Moreno, 2003). Evidence from the classroom observations indicated that biology teachers used iconic diagrams when they intended to introduce a new biological topic to students together with its background knowledge contexts before any formal instruction started. According to Novick (2006), photographs used in biology teaching can be classified under the category of iconic. Based on this criterion, the usage of photographs was found to be a prompt for the start of introductory remarks, which enabled students to have an advance organiser and thus to be presented with a focus on the content knowledge in the early stage of instruction.

Assertion 1a: Iconic diagrams helped teachers create the teaching contexts before the formal instruction starts.

Previous research found the necessity for learners to be able to combine multiple representations into an integrated knowledge structure, but before that, learners have to select what they perceive to be the most relevant aspects for further processing (Cook et al., 2008). Students' attention may need to be directed into perceiving what would be the topic of the lesson, and the process of extracting relevant information might draw heavily upon the first several representations provided by the teacher before any formal teaching.

While introducing the content '*Lives in The Water*', teacher K [K11litw9.11.10] showed a photograph of a creek with clean running water using the PowerPoint slide shown in figure 5.1 and then asked students questions like "where are we?...what can you find from this picture?" "Water ... a river" one student responded. Though most students remained silent in response to this simple question, everyone was waiting for the next PowerPoint slide. It was obvious that all students had reached a consensus about the teacher's question and their attention had been concentrated on the main content of this photograph, which is the running water. Students appeared to successfully understand the intention of this photo that enabled them to ignore other irrelevant items, such as the grass and rocks at the riverbank.



Figure 5.1 A photograph of a creek.

To assist students' understanding and generate more ideas about the content of this topic, teacher K further explored students' interests about the photo before he moved into the formal teaching session. He followed up by asking, "Anything you can find

in the water?... Is that water warm or cold?”. “Cold water”, another student promptly identified the temperature based on common sense. Indeed, the water temperature is one of the important variables affecting an organism’s life habits in the water environment. One of the aims of the intention to this lesson was to build students’ familiarity with the effects of temperature variations on the respiration rate of animals living in water. Students’ answers showed that they deliberately or unwittingly predicted what they might need to know about in the day’s lesson.

Assertion 1b: The teachers used iconic diagrams to introduce a biology concept that might not be familiar to students.

In the following example, an iconic diagram of a lemming (Figure 5.2.1) helped the teacher attract students’ attention on the main biological content of the lesson, namely *Sources of the Variation*. Subsequent to a background story about lemming illustrated by this iconic diagram, the teacher moved the focal point of his teaching onto the idea of *population variation*. The line chart (Figure 5.2.2) highlighted the general population fluctuation of this species, which was related to the iconic diagram and helped lead the instruction to the lesson’s focus. The simple hand drawn line chart was presented to students soon after the introduction of the photo, as it might supplement the previous usage of the iconic diagram or contribute to the better explaining of teaching on the whole.



Figure 5.2.1 Photo of lemming

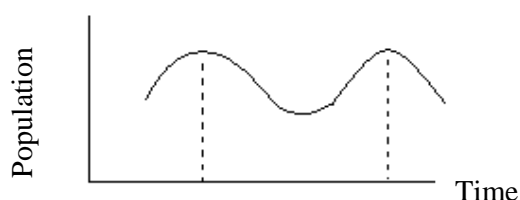


Figure 5.2.2 Population changes of lemming

Teacher D [D11sotv26.8.11]: As you can see, this is a mammal. And there is a rumour: they jump off cliffs and commit suicide... that’s nonsense. You know what I mean?

Students: Yeah.

D: I mean, there is a computer game on this too. Its name is

S: Lemming. (Only one student knew this animal and could answer the question, while others were reluctant to respond.)

D: Lemmings reproduce themselves so quickly but their population fluctuates dramatically, rather than following linear growth or regular oscillations. Lemming populations fluctuate before plummeting to near extinction. They just erupt and end up in the place where they can be found. And they come to a cliff and then it is the ocean. They jump off the cliff. So, what does it mean?

S: A large number has died.

D: Well done. That's really clever. Its population changes along with its habitat environment, weather, food, shelter, predators...That's Darwinism. He therefore included or asserted that individuals must vary. Does this mean that all species perfectly fit the environment?

S: No? I don't know why, I don't know.

D: They are not.

S: I guess some animals are well adapted to the environment.

D: Yeah, I suppose that's right. The species cannot be perfectly adapted, because the environment is always subject to change. There may be in the short term, and some in the long term. If you understand this, does anything else fill in the gaps? Most of the individuals are of high variation. What are the sources of variation? There are four types of possibilities: mutations, independent assortment, crossing over, random fertilization.

In the instance above, recognizing the lemming and learning about its physiological structure were not the main content of this biology lesson. Presenting the photo of a lemming gave students an example of a natural phenomenon that was relevant to how natural selection actually happened for a species. Furthermore, the line chart explained the information in detail and helped students better understand why the iconic diagram was presented. Therefore, the students obtained a sound advance organiser about the content and concepts that they were about to cover. Having students concentrate is not the ultimate goal for introducing iconic diagrams, for once the intention of the drawing has been perceived, students are able to organize their prior knowledge to readily and actively bring their imaginations into full play for the subsequent learning. The picture of the Lemming and the mysterious ideas associated with this gradually led the teacher's instruction into the main theories of the lesson – the *Sources of the Variation*.

5.3 FINDINGS OF THE OBSERVATIONS - ASSERTION TWO

Assertion 2: Teachers tended to use schematic diagrams and iconic diagrams interchangeably to facilitate the instruction of a concept and assess students' understanding.

Most schematic diagrams that were provided by the teachers appeared to correlate directly with the iconic diagrams that had been presented to students initially. Most of the biology concepts are explained at the sub-microscopic level, and basically describe what happens outside of our direct experience and the extent to which they can only be observed under a microscope. In order to help students fully understand the topic being taught, it is necessary to explore the understanding of biology concepts and phenomena and to constantly navigate between the macro and sub micro levels of representation.

Assertion 2a: Schematic diagrams tended to have a role to play in complementing the use of iconic diagrams.

Multiple representations complement one another with regard to information and processes (Ainsworth, 1999). More specifically, a second representation may be used to support learners as they interpret more complicated, abstract information (Tsui & Treagust, 2003). The researcher observed a tendency for teachers to draw upon schematic diagrams that employed the detailed and in-depth explanation for the concept being studied in class. For example, teacher K drew the sectional view of a cactus leaf on the board to show the position and function of the stomata when the topic 'Gas Exchange in Plants' [K11ge24.5.10] was taught. The leaf epidermis is covered with tiny pores, called stomata. Although the shape and appearance of stomata can be seen through a scanning electron micrograph (iconic graph), the process of gas exchange between the air and the photosynthetic cells inside the leaf has to be explained by schematic graphs showing the submicroscopic level.

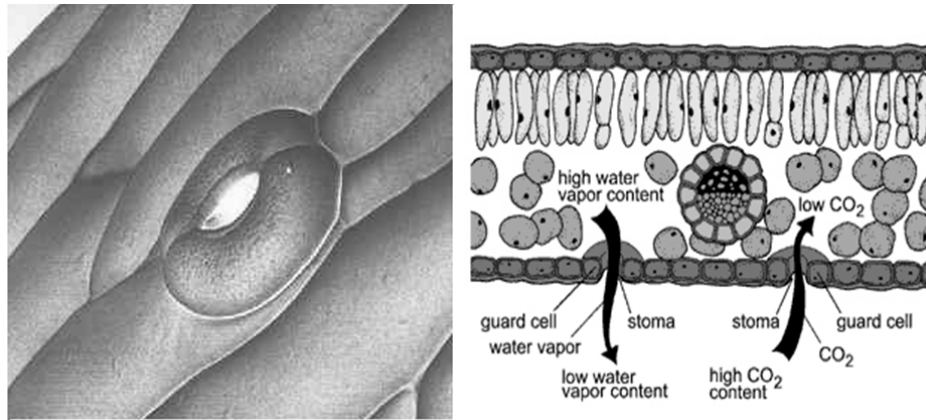


Figure 5.3 Iconic (left) and schematic (right) diagrams showing a single stoma (scale: 400×).

Students took it as a natural sequence to learn a new concept in the order of interpreting the iconic diagram first and then the schematic, for they believed instinctively that the former can always be easier interpreted according to their experiences and already formed conceptions. The new conceptions can be embedded within the old conceptions. By observing the changes that occur at the macroscopic level, students can be mentally and logically prepared to make sense of these changes at the submicroscopic or molecular level, since the schematic diagrams can help them view phenomenon that are not attainable in iconic diagrams.

One of the advantages of teaching with schematic diagrams in explaining biology concepts lies in the property of eliminating those redundant details and thus making the abstract process easier to understand. For example, it is difficult to explain the circulation of blood flow in the heart with an iconic diagram (see Figure 5.4), because the iconic diagram is so ‘real’ that students need to have spatial skills to figure out the atrium and ventricles. However, teacher B invented a schematic diagram for the reading on this topic “*The Cardiac Cycle*” [B11tcc27.5.10] and for a better understanding of the iconic diagram.

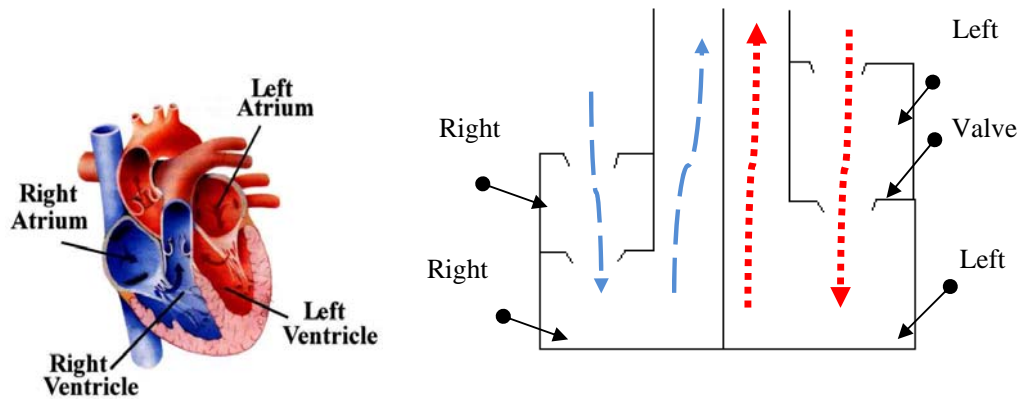


Figure 5.4 Iconic (left) and schematic (right) diagrams showing blood circulation in heart.

Teacher B: Blood from the body systemic circuit enters the right atrium. Meanwhile, blood from the lungs enters the left atrium. [Pointing at the top right part on the iconic diagram] Ok? From the atria the blood flows into the corresponding ventricles. That means from the right atrium to right ventricle; left atrium to left ventricle. [Referring to the direction of the blood moving from the top down] Happy enough?

Students: Yes.

Teacher B: The two ventricles on the two sides of the heart then contract and expel blood into the arteries. [Pointed from bottom up] Right?

Students: Yes.

Teacher B: To give you a clear picture of how the blood circulates between atria and ventricles, I am going to give you another chart. [Started to draw the boot-like schematic diagram of heart] I hope this one will be much easier for you to read. The blood leaves the left atrium to where?

Students: To the left ventricle.

Teacher B: From right atrium to?

Students: To the right ventricle.

Teacher B: Why is the left ventricle more muscular than the right ventricle?

Students: Because the left ventricle needs to contract harder and expel the blood into the whole body circulation.

Teacher B: Good. What is the role of the valves?

Students: To prevent the blood from flowing in the opposite direction.

For explaining the blood circulation in the heart, the teacher introduced the iconic diagram that is full of colors and details (on the left) and the schematic diagram that bears a much simplified structure (on the right). As students' understandings developed, the teacher kept asking questions trying to ascertain students' learning between both images. In this instance, the schematic diagram presents the same amount of content knowledge as shown by the iconic, but the information has been displayed in a different pattern. The schematic diagram eliminates the redundant visual details that may distract students' interpretation to reach the core information – the directions of blood circulation and the positioning of the ventricles and atriums. While students may retrieve some preliminary understandings from the iconic diagram, explaining with schematic diagram thus provides teachers with an additional pedagogical approach in complementing the teaching using the iconic diagram.

Assertion 2b: Teachers tended to spend relatively more efforts in explaining schematic diagrams.

During more than seven months of observations, it was evident that schematic diagrams are important in understanding certain biology concepts. Almost all biology teachers were found to devote a relatively long time in explaining the schematic diagrams that correlate with the iconic diagrams of the macro level in their lessons. The teacher's explanations might help students make connections between the concept at the macroscopic and submicroscopic levels. The iconic diagram on the top of Figure 5.5 shows the physical appearance of the neuron, whereas the schematic diagram of the Schwann cells at the bottom manifests both the structure of the Myelin sheath and salutatory conduction of a neural signal [D12ns12.5.11]. The teacher briefly explained the workings of the myelin sheath:

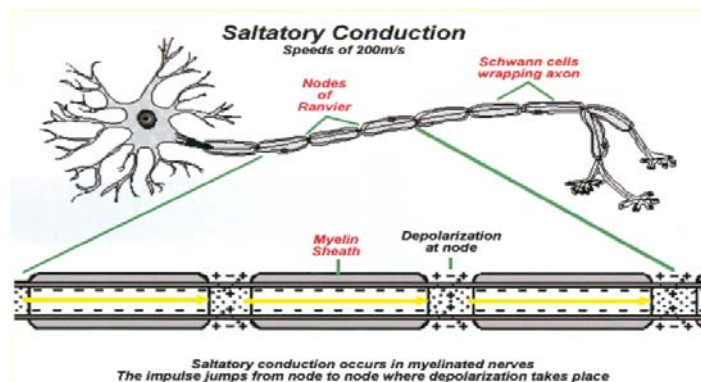


Figure 5.5 Both iconic (upper) and schematic (lower) diagrams have been employed in explaining the topic saltatory conduction.

A common characteristic of all living organisms is they can detect changes in their environment and respond to them. To detect a change or stimuli, some form of communication between different parts of an animal's organism is involved. There are two coordinating mechanisms in animals that control their responses to stimuli: hormones, and the nervous system. The nervous system is composed of cells called neurons, which specialize in carrying information. The shape of a neuron is shown in the above diagram. It possesses dendrite, an axon, and axon terminal at the end. [Teacher finished explaining the iconic diagram, and then referred to the schematic diagram.] The axon of a neuron is usually covered around with a layer, called a myelin sheath. The myelin sheath is essential for the neuron to transmit nervous signals properly. In the meantime, it provides protection for the axon being covered inside; it insulates the nervous impulse transmitted from other interference, thus to guarantee the accuracy and efficacy of signal transmission; and it helps increase the speed of the signal transmission through skipping every single Schwann cell, but by jumping from one node of Ranvier to the next node without increasing the diameter of the axon. [A metaphor has been introduced here to help explain the meaning of skipping.] Impulse jumps like a kangaroo and moves quickly from one node to another. And that makes the velocity of saltatory conduction higher than smooth conduction.

In the case above, the teacher explained the biological content with two diagrams one after another. In the very beginning, he referred to the iconic diagram on the top to

show students the physical shape of the entity - *the nervous system*. Student could have an idea about how the human organism responds to stimuli. The teacher also introduced some terminologies, such as *dendrite*, *axon*, and *axon terminal*. Students need to recognize the specific parts of the image according to the terms.

The teacher's instruction continued with the schematic diagram introduced to students, the explanation resumed by depicting the functioning roles of those entities within the nervous system. A schematic diagram was employed as it attempts to describe the transmission of the nervous signal that cannot be observed directly. The sub-micro level portrays the truth on a different scale, therefore it is not visible and more abstract to comprehend (Davidowitz & Chittleborough, 2009). Compared to iconic diagrams that have an advantage of showing matters at the macro level, such as representing the tangible biological substances or visible phenomena, schematic diagrams may have the attribute in providing some insight into students' understanding of the underlying mechanism and principles embedded behind the phenomena. In this investigation, the teacher shifted his explanation of content knowledge from using the iconic to the schematic diagram, students need to develop their conceptual interpretation by relating both of the diagrams. An implication of this study is that teachers may spend more efforts in explaining the schematic diagrams during the overall diagrammatic usage.

In a similar manner, there was evidence that teacher K emphasized the understanding of the schematic diagrams about the *Human Respiratory System* [K12hrs 8.6.11] when both iconic and schematic diagrams were employed in this lesson. Without a doubt, the sub-microscopic processes and the abstract nature of this biology concept created the need for most of the visual attention and efforts being focused on this level, because conceptual learning was considered as students' thinking transitioned between the macroscopic and microscopic representations (Chittleborough & Treagust, 2007). Learners' misinterpretation of diagrams may occur when links are not made between the macro and sub-micro levels, moreover, the connections between the macroscopic level and the sub-microscopic level are not always apparent and explicit to students (Davidowitz & Chittleborough, 2009). These findings seem to be consistent with the researcher's observations, which found biology teachers emphasized the transition of students' understanding from the macroscopic phenomena level to sub-microscopic thinking level. It can thus be suggest that

teachers paying more efforts in explaining the schematic diagram that may serve as a basis for students to construct the connections between the macro and sub-micro level in their mental models for the concept.

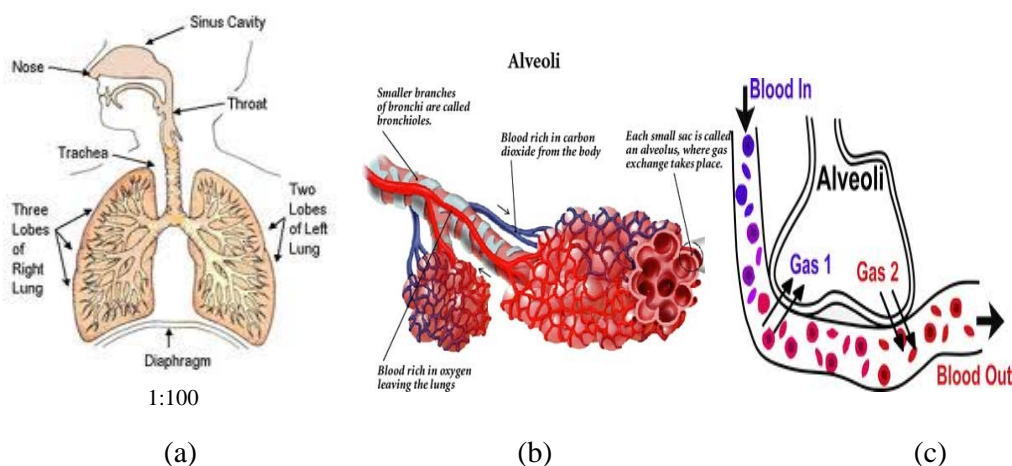


Figure 5.6 Gas exchange in alveolus – macroscopic (a) and submicroscopic level (b and c)

Having examined the biology topic – *Human respiratory system* explained by the combination of iconic and schematic diagrams, this finding corroborates the idea that biology teachers appear to take for granted that a certain number of schematic diagrams should be implemented this helps students with their interpretation of the corresponding iconic images and eventually assists the efficacious instruction of biological knowledge.

In *Figures 5.6*, the images (b) and (c) depict a representation of the sub-micro level. They are used to help understand the unseen sub-micro level of representation such as the blood circulation and gas exchange in alveoli. The blood circulation and gas exchange are important facts that need to be understood in order to gain a better understanding of what happened under the macroscopic level as shown in the first image. Therefore, details and accuracy are provided by the two schematic diagrams to understand the sub-micro level of the biological entity – the alveoli. Instead of assuming that students will absorb the sub-micro information presented in the schematic diagrams, the teacher guided students to a full understanding by

explaining the information at sub-microscopic level. The teacher explained the gas exchange in the alveoli:

... Let's follow a breath of air from start to finish. [Pointing at the nose on the Figure 5.6 (a)] The air goes into the nose or mouth and goes into the trachea or windpipe.

The end of your trachea splits into an upside down Y-shape and forms the bronchi. Air passes through the windpipe and reaches both sides of the lungs. And the lungs are protected by the ribcage. [Teacher finished the explanation of the physical features and then switched to the schematic diagrams]

Inside of the lungs, the bronchi branch off into lobes, which look similar to branches of a tree. The air flows through the bronchioles until the air reaches the ends of the branches, which are clusters of little pockets that have the form of hollow cavity, called alveoli. Alveoli are the final branches of the respiratory tree and act as the primary gas exchange units of the lung.

The blood brings carbon dioxide from the body and releases it into the alveoli, and oxygen in the alveoli will be taken up and transported to the cells all over the body. [Teacher explaining the direction of blood flow in figure 5.6 (b)]

[Teacher started to explain the gas exchange in figure 5.6 (c)] When the air reaches the alveoli, oxygen (Gas 2) diffuses through the membrane into small blood vessels called capillaries, and carbon dioxide (Gas 1) diffuses from the blood in the capillaries into the alveoli.

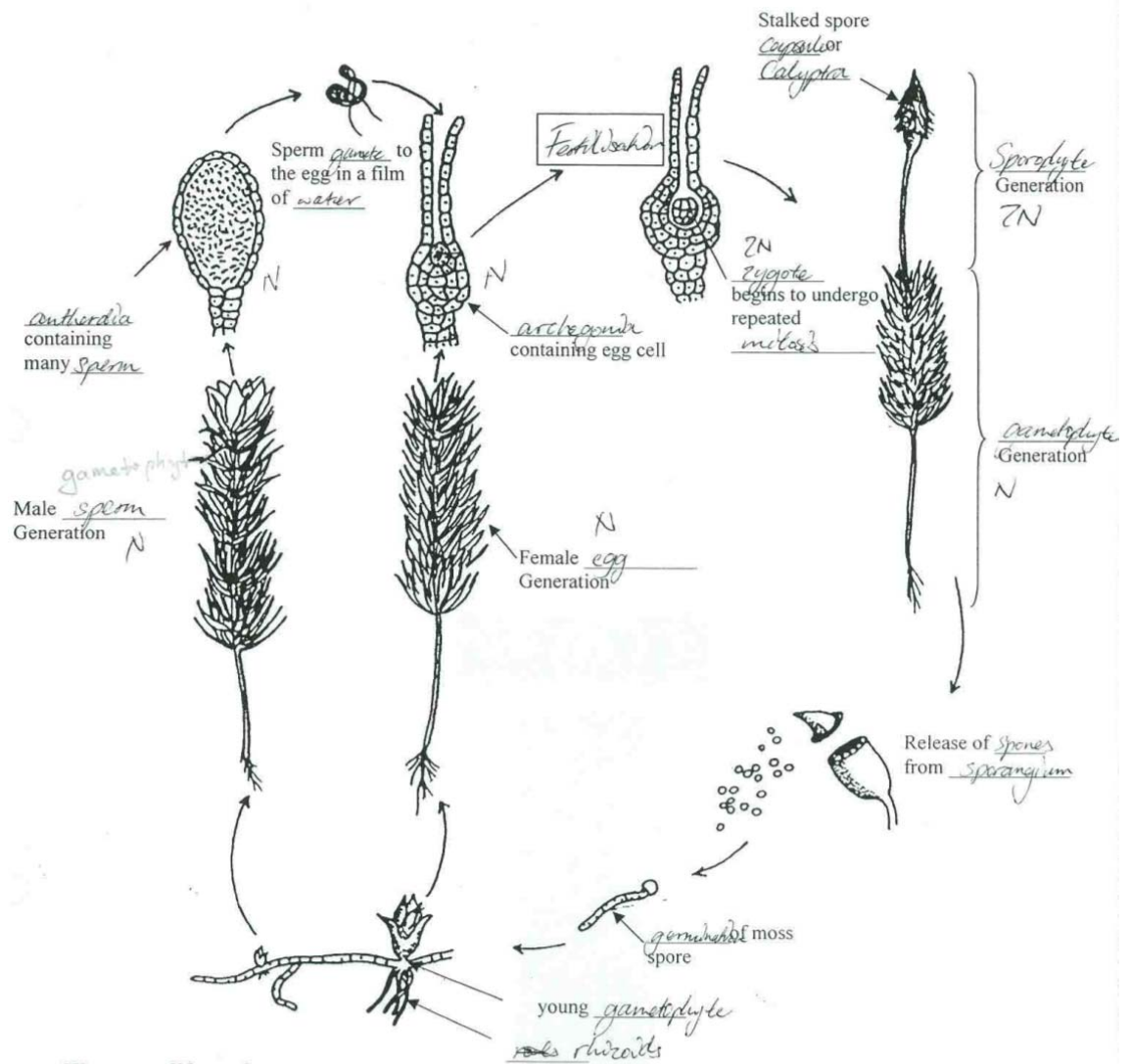
Once the teacher finished the explanation of the iconic diagram (figure 5.6 a) for the physical characters of the lungs, he immediately turned to the schematic diagrams (figure 5.6 b and figure 5.6 c) to introduce the submicroscopic features to students, such as the directions of the blood exchange and how the gas exchange happened in the alveoli. The difficulty that students face in interpreting and visualizing the biology concept's submicroscopic features thus appeared to be reduced, since schematic diagrams actually facilitate the prior knowledge received by the iconic diagram. As soon as the students have their prior knowledge activated from those macroscopic features embedded in the iconic diagram, they are expected to be able to construct an integrated understanding that coordinates the transitions between

macroscopic and molecular levels. The connections between the macroscopic and molecular levels in this case may refer to the holistic understanding of how oxygen and carbon dioxide exchange in the alveoli.

This observation has confirmed the cohort relationship between iconic and schematic diagrams in illustrating certain biology content knowledge, as they have been jointly introduced by the teacher's instruction. This also accords with the earlier observations that students depend on iconic diagrams to recognize macroscopic features of the biological entities. Soon after, schematic diagrams may have a role to play in showing learners with the sub-micro level of the conceptual learning. From these findings therefore, it can be assumed that teachers tend to spend more efforts in emphasizing students' learning with the schematic diagrams due to the nature of learning the sub-micro level depends on being consistent with the interpretation of macroscopic learning. Teachers switching between iconic and schematic diagrams provide opportunities for students to construct scientific personal mental models that interconnect with different levels of conceptual learning.

Assertion 2c: Teachers used schematic diagrams to assess students' understanding.

Data also emerged supporting the notion that schematic diagrams could help teachers assess students' learning during their classroom teaching. In teaching the '*Moss Life Cycle*', students were requested to label and answer the questions on the worksheets/handouts (see *Figure 4.2.8*). Though many simple drawings were used in depicting the appearances of moss in different phases, the whole life cycle is shown by this compound schematic diagram that consists of a number of iconic diagrams. Teacher K [K11mlc23.8.10] went over the biological content orally by asking students to label each part of this synthesized schematic diagram part by part.



The moss life cycle

1. Indicate where meiosis occurs in this life cycle?
2. Show which structures are haploid and which are diploid by using N and 2N.
3. Colour in red the structures associated with the sporophyte generation.
4. Colour in green those structures associated with the gametophyte generation.
5. What is meant by 'alternation of generations'? *Between gametophyte and sporophyte generations.*
6. On the back of this sheet, write a paragraph describing the events of this life cycle.

Figure 5.7 Schematic diagram of Moss life from student worksheet

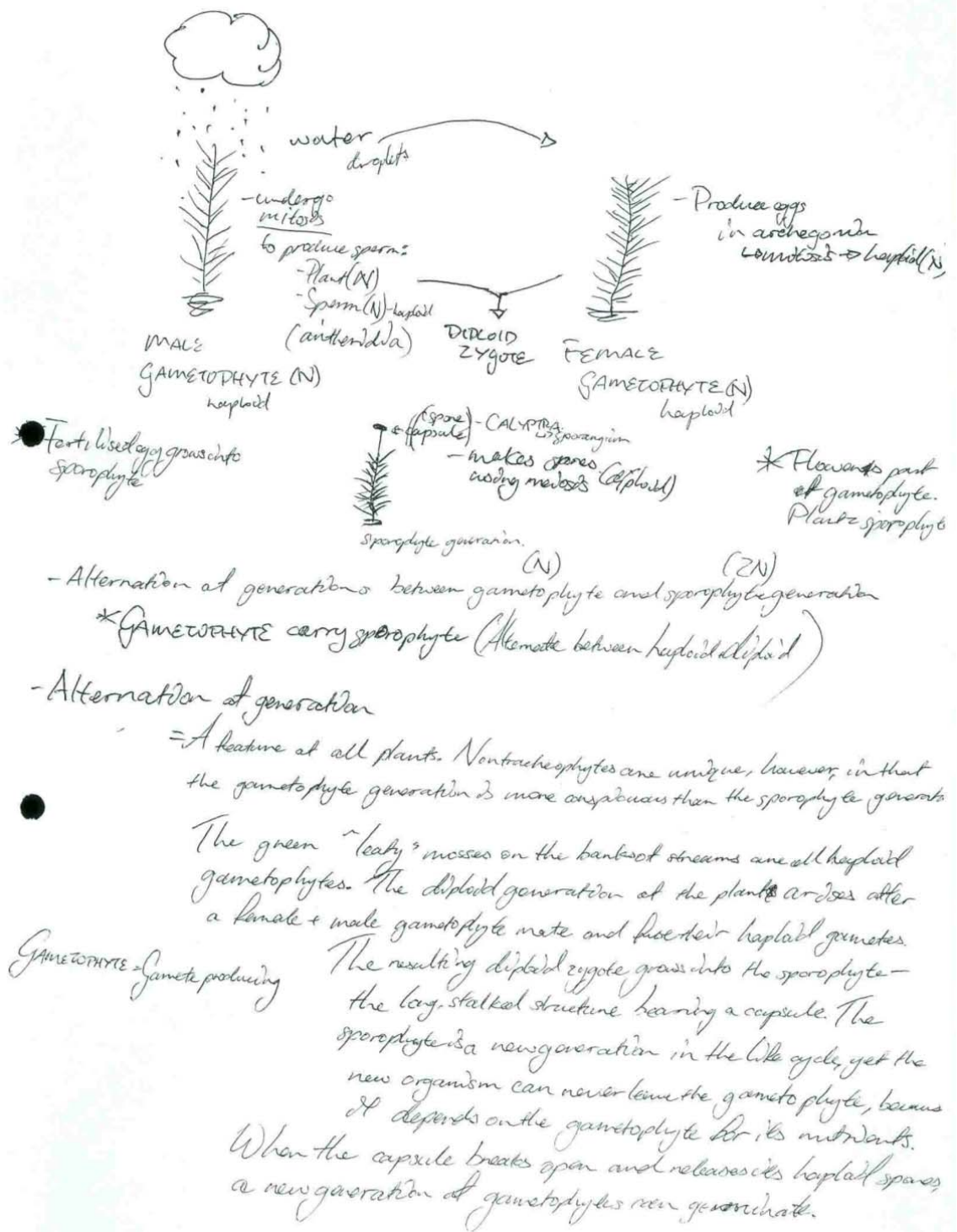


Figure 5.7(continued) Schematic diagram of Moss life from student worksheet

T: What generation is the moss you see? What generation is that?

S: Mitosis

T: That is the gametophyte. It produces gametes. There are male and female in your diagram. Can you put down gametophyte for male? The female generation is also gametophyte, is that right?

S: Yeah.

T: Because there are male and female plants. The gametophyte virtually has got sex organs that produce sperm. What do you call the male sex organ of this moss? Something containing sperms. What type of sperm, haploid or diploid?

S: Haploid.

T: Haploid sperm. Haploid gametophyte produces these sperm by mitosis. Like the sperm, the eggs are haploid and are produced by mitosis. Sperms swim through moisture form antheridia to eggs in the archegonia and then fertilize the eggs. Fertilization can produce a diploid zygote, the birthed generation is called sporophyte generation, and the young plant grows out from an archegonium of its parent, the gametophyte. When the top of the sporangia shed, spores are released to the wind.

T: Let's go get a conclusion, can you read that? Are you able to label all this everybody?

S: No.

T: Which one you don't know?

S: The one in the box on the top.

T: That one we call it fertilization.

S: What is the one after the fertilization?

T: That is zygote begin to undergo repeated mitosis. Here you got two parts: the top one is sporophyte, the bottom one is the gametophyte. If you put your hands on the surface, you can feel those stalks sticking out. [The teacher attempted to relate the conceptual instruction with students' everyday experience] The top of the cup can release of what?

S: spores. [Students gave the correct answer]

T: Can we call it haploid spores? Because the spore is sporangium undergo meiosis. And the germination of spore gives young gametophytes. That part of the root is not actually roots. In ferns, these are the wood like rhizoids. Question number 5, what is meant by 'alternation of generations'?

S: The alternation of sporophyte to gametophyte.

T: An alternation of spores producing sporophyte generations, followed by the gametes producing gametophyte generations.

The schematic diagram in Figure 5.7 drawn by one student indicates the reproduction process of moss, in which students need to recognize and label every single stage of the moss life cycle illustrated by the drawings. The preliminary requirement for the

student is to know what the biological entities stand for, and then to relate the entities to the events that happen in a sequence. Thus, the advantage that schematic diagrams have in providing concise depiction of a complicated process has been employed in assessing students' learning: on the one hand, students need to remember the terminologies and match them with each entity correctly; on the other, it is more demanding for students to relate every single parts in the schematic diagram and generate a complete interpretation about the biological concept.

There was more evidence from the lessons observed that schematic diagrams were employed for assessing students' learning. Teacher's questions were closely related to the content been taught during the class. In teaching genetics, the teacher introduced the background knowledge and explained the definitions of terminologies such as genotype and phenotype. Afterward, students were requested to answer the questions on the worksheet immediately. Though the examining process was not a formal pencil and paper test, it served as a complement to the teaching and hence reinforced students' learning of the content knowledge.

T: For humans, height is determined by quite a number of genes, that's why people are in between, several ranges of height. There are tall pea plant and short pea plant. Tall means tall, short means short, there is no in between. It either can be tall plant or short plant. So, phenotype means physical appearance. so if a tall plant is crossed with dwarf , and the parents genotypes will be TT and tt. If the genotype is TT, then how would you describe the plant? (pointed at the Table 5.1 on the blackboard).

Table 5.1 Pedigree chart of pea plant

Parents: phenotypes	Tall	↔	Dwarf
genotypes	TT		tt
Possible gametes	T and T		t and t

S:....

T: Is that homozygous or herterozygous?

S: homozygous.

T: And the shorty, the dwarf is obviously homozygous too. Because if you are recessive, you are homozygous. If you are Tt, you are tall. So you get a pure breed tall cross with pure breed shorty. The gametes from the tall will be big

TT only, the gametes from the short one will be tt. What will you get for the first generation in the Punnett square?

S: Heterozygous, Tt.

T: Good. I am going to ask you a question: is genotype determines the phenotype or phenotype determines the genotype?

S: Phenotype the genotype. (students had different answers to this question) .

T: The genes determine what you look like. The genotype determines the phenotype. Phenotype cannot change the genes. Homework, can you answer the questions 1-6 (See Figure 5.8):

The teacher finished his explanation on distinguishing the biological terms and then asked students to finish the worksheet (See Figure 5.8). Students then needed to work out the questions according to the method they have learnt about calculating the possibilities of gene inheritance. The teacher's revision and questions raised are included as follows:

T: The father is X^hY , Ok? The mother can be $X^H X^h$. Now can you answer those questions 1-6 down? Haemophiliac is someone who doesn't have the gene producing enzymes to block the injured vessels.

S: Is number 7 a carrier or a haemophiliac?

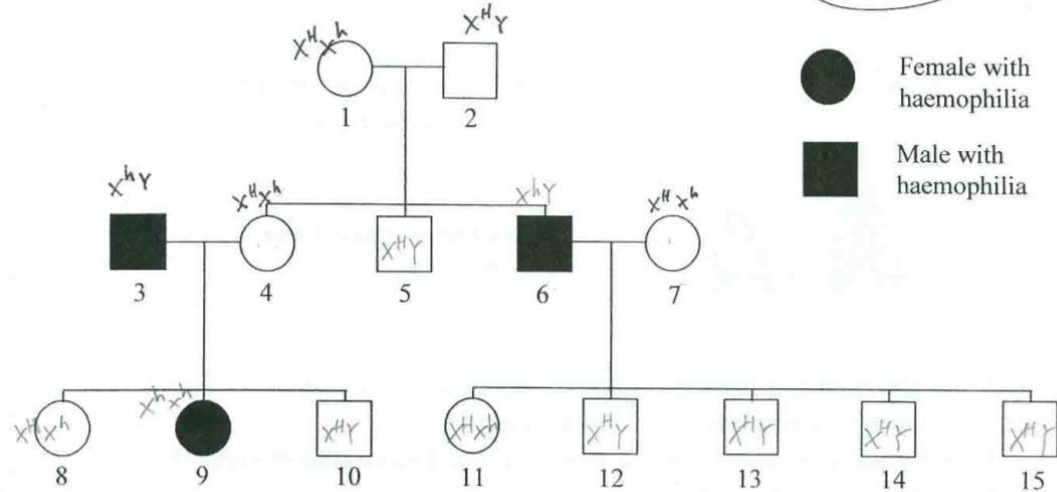
T: The individual 7 is more likely to be $X^H X^h$, because none of their offspring suffered.

S: If 6 and 7 had another child, the possibility that it would be a carrier.

T: If 7 is that type, then there is a possibility. What happened is, if 6 is X^hY , 7 is $X^H X^H$, what is the chance to be a carrier? The story would be different. Let me draw on board.

SEX LINKED GENES

FAMILY TREE SHOWING HOW HAEMOPHILIA IS INHERITED



QUESTIONS:

1. Give the genotype of each individual in the pedigree chart.

STEPS:

- Use X and Y to show sex.
- Use symbols 'H' and 'h' to label the genotype of those you are certain about.
- A male will only get 'H' or 'h'. A female can be HH, Hh or hh.
- Complete the chart.

2. Which individuals are 'carriers'? 7, 8, 11
3. What is the sex of these carriers? female
4. If 3 and 4 had another boy, what is the chance that he would be a haemophiliac?
i.e. $X^h Y$ 0
5. If 3 and 4 had another daughter, what is the chance that she would be a haemophiliac? i.e. $X^h X^h$ 100%
6. If 6 and 7 had another child, what is the chance that it would be a carrier? i.e. $X^H X^h$ 100%

Figure 5.8 Schematic diagram used in assessing genetics from student worksheet (hand written comments are one student's responses)

5.4 FINDINGS OF THE OBSERVATIONS - ASSERTION THREE

Assertion 3: Analogical explanation was frequently engaged in by the teachers while teaching with diagrams.

Analogy's potential as a powerful tool for educational purposes lies in making the instruction of new material intelligible to students by comparing them to that is already familiar (Orgill & Bodner, 2005). According to the observations, about 90%-95% of the diagrams that were presented by the teachers appeared to help students develop a conceptual understanding of biological entities and processes that were too abstract to be represented in the classroom or observed by the naked eye. Being an omnipresent learning resource to students, there is a tendency for the teachers to draw upon analogies that either come from the learners' knowledge base or experience of daily life (Treagust et al., 1998). Examples are provided in the following assertion:

Assertion 3a: Diagrams tended to share analogical features if an analog relation could be used for representing data.

There was evidence in the classroom observations that teachers used analogies when they were having difficulty explaining some aspect of a diagram or the biology concept. Often, this was a prompt for providing an analogical explanation. The researcher also noticed that a number of attributes from students' prior knowledge or familiar concepts were transferred to help recognize the target concept. For example, the neuron has been compared to cable wire; the sprout of fern to a fiddle head as described in Table 5.2.

Table 5.2 Selected Analogies Used by the Biology Teachers during the Lessons Observed

Topic	Teacher	Grade	Analog	Target	Explanations
Nervous Control	Teacher K	12	Cable wire	Vertebrate neuron	1. Neural signal has single direction transmission. 2. Structure of the single nerve cell – axon is covered by layers of myelin sheath.
Vegetative reproduction	Teacher K	12	Fiddle head	Sprout of fern	External shape and appearance look alike
Nervous Control	Teacher K	12	German sausage	Myelin sheath	1. Shape and appearance look alike. 2. The sheltering effect – Schwann cells shelter the axon.
Vocal apparatus	Teacher K	12	Honda's logo	Adam's apple	Shape and appearance look like "H"
Enzymes	Teacher D	11	Lock and key	Enzyme and substrate molecule	1.Simple external appearance matches 2.Explanatory structures transferred – one type of enzyme corresponds to one kind of molecules.
Respiratory system	Teacher K	12	Mexican walking fish	Lung lobe	Shape and appearance look alike.
Filtering function	Teacher D	12	Pencil case	kidney	Kidney picks up things selectively.
Human blood	Teacher K	9	Biconcave disc	Red blood cell/erythrocyte	Shape and appearance look alike.

The examples in Table 5.1 also appeared to have a motivational impact on students. In the learning process, the strength of analogies lies in their abilities to provide additional visualization of abstract concepts and to compare similarities between students' prior knowledge and the target concepts (Gilbert, 2005). Seeking to ascertain analog familiarity and providing analog explanation appeared to reduce the effect of the original analog unfamiliarity. As has been described above, those concrete analogs are akin to the daily life condition that facilitates students' learning by providing visualization of abstract concepts to be conceptualized. Students also found it interesting when they could find some non-biological entities that bear the similar properties of the concept they just learned. The frequent uses of analogical visuals make the biology instruction much easier and enjoyable to the teenager students. Because analogies can be used to liberate certain ways of viewing the concepts being studied and link between existing conceptual frameworks and those associated with new knowledge (Orgill & Bodner, 2005).

The researcher noted that when students appeared to have difficulty in understanding a certain complicated or completely new biological concept, an analogy will often be introduced to transfer some or part of the appropriate attributes from the analog to the target domain expertise. For example, when teacher K explained the anatomical structure of neurons, an analogy was used:

You can imagine this is a cable wire [Students laughed]. Sensory neurons are activated by the stimuli such as light, sound and temperature [Teacher tapped one end of the cable in his hand]. It is a one-way, single direction transmission, the signal goes from the outside environment to the internal central nervous system. The axon is covered by layers of myelin sheath. Let's say the metal part of the cable is covered by the rubber skin.

In teaching with this analogy, the researcher noticed that the neuron concept was so abstract that students might not be very interested. The classroom appeared to be very quiet and didactic until teacher K introduced this analogy that made students burst into laughter. The introduction of the analogy cable wire was appropriate and on time, because it attempted to address the following aspects: 1) direction of the signal transition and 2) structural similarity. As has been described above, the analog familiarity and providing analog explanation appeared to reduce the level of difficulty of interpreting the concept being taught. Students also became motivated and more willing to learn.

Assertion 3b: The teachers tended to draw upon their own experiences or their own professional reading as a source of extended analogical explanation for diagrams.

One of the intentions of the research was to examine different types of diagrams used in teaching biology and to find out how the understanding of biology concepts through diagrams could go hand in hand with extended analogical explanation. For the majority of diagrams presented in the process of classroom instruction, teachers used a great amount of analogical explanations as an aid to students' imagination transitioned between different levels of representations. As described earlier, analogical explanation was always necessary in response to the students in understanding both diagram and the concept.

The teachers' sources of analog were quite varied. Teacher K had developed a considerable repertoire of analogies over several decades of teaching, many of which he had developed from his extensive professional reading. As an experienced biology teacher he was able to improvise many of his analogs. Sometimes, he even adopted multiple analogies to help explain a single biology concept shown by a diagram. Teacher D demonstrated his sources of analogies partially coming from a biology curriculum package/ teachers' handbook and a few came from the web. In general, almost every biology teacher taught with his/her self - designed diagrams that have analogical features employed and were shown either on the computer screen or were hand-drawn on the whiteboard as is summarized in Table 5.3.

Table 5.3 Summary of Diagram and Analogy Sources

Teacher	Target student	Sources of diagrams & extended analogical explanation		
		Teacher's handbook	Online resources	Improvisational
Teacher K	Year 11, 12	✓	✓	✓
Teacher D	Year 11, 12	✓		✓
Teacher B	Year 9, 10	✓		
Teacher C	Year 9, 10	✓	✓	
Teacher S	Year 9	✓		

In the observations, the researcher observed that teachers tended to adopt analogical explanations while teaching biology with diagrams. The combination of diagrams and analogies were found to have the potential of facilitating students' development of in-depth understanding of the topic. In some of these instances, teacher K explained biological concepts to students who initially had difficulty to interpret diagrams' connotation correctly or completely. Teacher K was observed to turn to analogies for some references which were closer to students' experiences. All of these analogies were functional in nature and were different to conventional models where structural attributes are simply exaggerated. For example, as indicated in Table 5.1, "Myelin sheath" has been compared to "German sausage". This analogy may suggest that teacher K was more willing to use this analogy in emphasizing the structural similarity and appearance resemblance between the analog and the target concept. In teacher D's class, the "pencil case" has been used in referring to the kidney when he explained the concept *kidney filtration*. Although pencil case does not look exactly the same as the kidney, this analogy was to have students understand how the kidney selectively filtrates substances.

This evidence from observations confirms previous findings that analogies allow teachers to consider students' prior knowledge and therefore facilitate understanding the abstract by pointing to similarities; incite learning interests and have a motivational function in representational learning (Ainsworth, 2008a). The analogies together with diagrams tended to help those students generate in-depth understanding about the concept. Analogies are essential to the use of diagrams, they provide a way of helping the students explain and communicate information. In the practice of biology teaching, the communicative function of analogies tend to be used for facilitating visualization of the abstract concepts that are embedded within diagrams that students might have difficulty in making sense of (Novick, 2006). Similarly, the interpretation of analogies encourages students to think about the joint collaboration of diagrams and analogies for the instruction of biology concepts.

Teacher K introduced the analogy Mexican walking fish (see in Table 5.1) during the depiction of the lung lobes, as both entities have innumerable fine branches stretched out. [The researcher believed that students were familiar with Mexican walking fish because its image has appeared on the cover page of one biology textbooks and no one doubted the name of this species].

Teacher K's intention was to have students imagine the shape of human lung lobes based on their pre-exist knowledge – the image of external gills on the Mexican walking fish. When teacher K was using this analogy, the students immediately understood this humorous comparison [Some students raised up their heads with a satisfactory smile, expecting teacher's further explanation].

The example above indicates that the image of the Mexican walking fish has provided an analog that assisted students' interpretation of the concept to be learnt. Students' interpretation of the analogy thus helped student make connections between the image of the analog and the target concept. Another possible explanation for this is that analogies may help students visualize abstract concepts, orders of magnitude, or unobservable phenomena (Orgill & Bodner, 2005).

5.5 FINDINGS OF THE OBSERVATIONS - ASSERTION FOUR

Assertion 4: Text appeared to help iconic diagrams elaborate biology content knowledge.

When a single static diagram has difficulty conveying a complex meaning, especially a holistic process that may have many factors involved, an appropriate combination of representations can help achieve a better learning outcomes. Figure 5.9 is drawn from Teacher K's PowerPoint slides on the topic 'blood circulation' [K11v18.6.10]. When the teacher introduced the topic "vasodilatation" to explain the changes of heat loss, he asked students if they were able to find the corresponding movement of blood vessels according to the changing temperature of the body through merely reading the diagram.

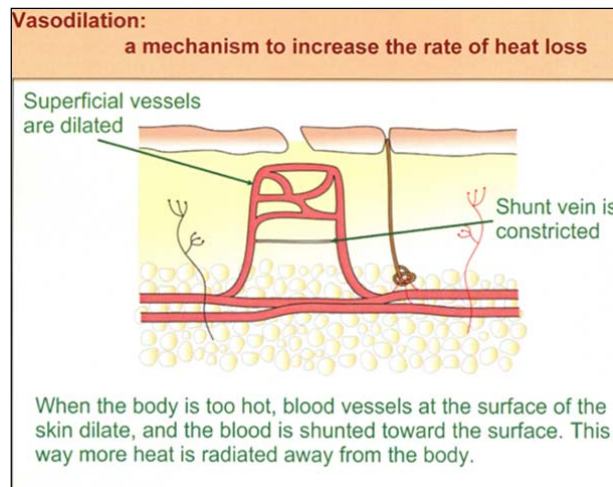


Figure 5.9 Diagrammatic and text are used in explaining vasodilatation.

Receiving several responses to the negative, he briefly explained the function of vasodilatation by pointing to and explaining the diagram as detailed below:

Teacher K: You can imagine the feeling of your body temperature increase. How can the body temperature increase? [Pause while he awaits students' response.]

Students: Playing basketball or football.

Teacher K: Yes, sport makes the blood become hotter, and the skin of our body needs to make the evaporation process go faster so as to let the heat go out of the body. In this case, should the superficial vessels go closer or stay away from the surface? [Pointed at the diagram and showed the direction of dilation of the vessels.] That is what happens when you are playing basketball, your face gets flushed and you sweat more.

It is increasingly recognized that learning with multiple representations is more effective than learning with a single representation, since each mode of representation has its own advantage of presenting a certain type of information (Waldrip et al., 2010). In this case, static diagrams have difficulty in presenting the dynamic dilatational process of vasodilatation. Learners could misinterpret the process because they cannot identify the dilation of vessels from the diagram. In this case, a second and more familiar form of representation can support learners in constructing a deeper understanding of the first complicated representation. By reading the text underneath and switching between the diagram and the text, students may gain a brief understanding of the mechanism of vasodilatation.

5.6 SUMMARY

This chapter has reported interpretive research into biology teachers' use of diagrams. Eight assertions have been drawn from this section into biology teachers' pedagogical use of diagrammatic representations to explain abstract biological concepts. In brief, the four main assertions summarized from these classroom observations were:

- Iconic diagrams helped teachers introduce a new biological topic together with the knowledge context to students.
- Teachers tended to use schematic diagrams and iconic diagrams interchangeably to facilitate the instruction of a concept and assess students' understanding.
- Analogical explanation was frequently engaged in by the teachers while teaching with diagrams.
- Text appeared to help iconic diagrams elaborate biology content knowledge.

Subsequently the findings guided the implementation of the further study related to the assessment of students' perceptions on biology teachers' use of diagrams.

The following chapter investigates the third research objective of this study – construction of an instrument to investigate students' perceptions on teachers' instructional use of diagrams. It is argued that richer data should be obtained from the textbook analysis and the observations of teachers using diagrams in the naturalistic setting of the classroom. Chapter six moves on to the investigation of the diagrammatic teaching and learning from the perspective of students and will explore the reflections that students have about the overall diagrammatic instructional environment is what they have been exposed.

CHAPTER 6

THE DEVELOPMENT OF AN INSTRUMENT TO MEASURE STUDENTS' PERCEPTIONS OF BIOLOGY TEACHERS' DIAGRAMMATIC USAGE

6.0 CHAPTER OUTLINE

The past two chapters have described the research findings about the use of diagrams in secondary students' biology textbooks and during biology teachers' classroom teaching. These studies employed an interpretive research style to ascertain what and how different diagram types were used in the teaching and learning of biology. The previous chapter examined teachers' instructional use of diagrams that are employed during the explanation of biological concepts in classroom situations. In this way, the research attempts to keep a record of teachers' use of diagrams within the naturalistic setting of the biology classroom so that the findings should be more readily transferable to other school settings.

This chapter describes the third phase of the research program. Chapter six reports the investigation related to research question 5: What are the major dimensions that biology teachers need to be aware of when diagrams are used in their teaching, and research question 6: What are students' perceptions of teachers' instructional strategies with diagrams? This chapter discusses the process used to develop the instrument, which included observing teachers' teaching practice to identify the salient features of diagrammatic teaching, adapting a previously validated instrument, improving the instrument, and administering it. The researcher considered it important that such an instrument be designed in association with the diagrammatic teaching and learning setting of the biology classroom.

6.1 RATIONALE FOR DEVELOPING THE INSTRUMENT

Diagrams are powerful for illustrating various natural phenomena and are an essential tool to understand and convey scientific information in science journals, newspapers, and magazines (Cheng & Gilbert, 2009). Especially in biology, diagrams play a prominent role in communicating and teaching important concepts.

Studies have found that there are numerous photographs, diagrams and naturalistic drawings on almost every page of biology textbooks (Pozzer & Roth, 2003; Roth et al., 1999). The researcher also spent a great amount of time inspecting the visual images contained in the secondary general science and biology textbooks and observing how those diagrams were employed in teachers' teaching practice (see chapters 4 and 5).

Although diagrams are beneficial and widely used in science classrooms, students often encounter difficulties in interpreting diagrams or finding the relations between the illustration and the concepts they represent. A different level of abstraction in diagrams is among many factors affecting students' understanding. Novick (2006) and Roth and his colleagues (1999) noted that diagrams usually delete less important (or less relevant) information to the main concept and this may contribute to students' difficulty. Without knowing those interpretation conventions, one may not be able to attain expertise out of the diagrammatic representation.

Since different types of diagrams have their own unique advantages in conveying information and guiding learning, it is necessary for teachers to consider the following issues in their teaching: How do my students perceive diagrams in relation to the biology concepts I have been trying to teach? How do the diagrams I have been using in the teaching really work for my students' benefit? How competent do my students feel in interpreting and drawing diagrams for their learning? The instrument was designed to help students reflect upon their use of diagrams during the teachers' instruction. Moreover, students are in a good position to form accurate impression about various learning environments they have encountered (Fraser, 2012). Therefore, the researcher believes that it was worthwhile to develop an instrument exploring students' perceptions.

6.2 DESCRIPTIONS OF THE DEVELOPMENTAL PHASES

The development process of the instrument included several phases which are described as follows:

Phase 1: Identifying the salient characteristics of teaching approaches in the multiple representational learning environments.

Phase 2: Seeking any available instrument and writing the items for each scale.

Phase 3: Seeking biology teachers' opinions and revising the instrument accordingly.

Phase 4: Administering the questionnaire and analysing the data.

Phase 1: Identifying the salient characteristics of teaching approaches in the multiple representational learning environments.

In the first phase of development, the efforts were spent on identifying and defining the nature and the characteristics of teaching with diagrams in the multiple representational learning environments. The researcher conducted a review of research on the functional value of multiple representations for science teaching and teachers' pedagogical content knowledge. References were made to a previously validated instrument SPOTK (Tuan, Chang, Wang, & Treagust, 2000), which identified four categories of students' perceptions on teachers' knowledge: 'Instructional Repertoire', 'Representational Repertoire', 'Subject Matter Knowledge', and 'Knowledge of Students' Understanding' (See Table 3.2).

The reference to the previous valid instrument and the observations of biology teachers' diagrammatic usage in the classroom led to the choice of four scales for inclusion in this survey. For this study, the four scales were initially retitled: Instructional Repertoire, Representational Repertoire, Assessment Repertoire, and Competence Repertoire.

The Instructional perspectives focused on the generic teaching practice with diagrams, which involves the details such as whether a variety of diagrams have been included in explaining the concept, the sequence of introducing diagrams, or if other modes of representations have been used together with the diagram. This perspective summarised a great deal about the pedagogical role of diagrams in teachers' teaching.

The Representational perspective aimed at the representational features of diagrammatic teaching. Though diagrams are representations that provide information, not every diagram depicts reality in exactly the same way. With the representational features, diagrams can help students to visualize complex biological or physical phenomena which are often hidden from the direct observation and

experiences. In this regard, the representational dimension contains a set of rules or methods that guide students' interpretation between the diagram and the concept been represented.

The Assessment perspective is how diagrams can be utilized in evaluating students' learning. According to the findings from the textbook analysis and classroom observations, diagrams can play a prominent role in assessing students' conceptual learning. This assessment perspective emphasises the functionality that diagrams have in helping teachers check students' conceptual learning. For instance, a diagram can be used in teacher's evaluation while the teaching is in progress; models can be used to check students' learning.

The Competence perspective addressed the essential techniques and skills for learners to interpret diagrams. As interpretation conventions are critical for understanding and using diagrams, students may not be able to attain the domain knowledge only by learning the diagrammatic representation. Specific conventions are required for students' attainment of the biological expertise embedded in different types of diagrams. Therefore, the competence scale includes the issues like the distinguishing the static and dynamic information and learning sequences starting from less abstract diagrams.

Development Phase 2

The second stage was to write the items under each scale identified in phase one. References have been made to the previously validated instrument Students' Perceptions of Teachers' Knowledge (Tuan et al., 2000). Some items were adapted to fit the representational teaching and learning environment where possible. Table 6.1 shows the items adopted from the original scales and items (Tuan et al., 2000). Particular interest was to determine if the scales reported by previous studies will hold up when the focus is placed on teaching biology with diagrams. A five-level Likert scale was adopted in the response format, namely strongly disagree, disagree, not sure, agree, and strongly agree.

Table 6.1 Items Adopted From the Original Scales and Items of SPOTK (Tuan et al., 2000)

Assessing students' perceptions of teachers' knowledge (SPOTK)		Assessing students' perceptions of biology teachers' diagrammatic usage (SPOBTDU)	
Sales	Items	Scales	Items
IR	1. My teacher's teaching methods keep me interested in science. 2. My teacher provides opportunities for me to express my point of view. 3. My teacher uses different teaching activities to promote my interest in learning. 4. My teacher uses appropriate models to help me understand science concepts. 5. My teacher uses interesting methods to teach science topics. 6. My teacher's teaching methods make me think hard. 7. My teacher uses a variety of teaching approaches to teach different topics. 8. My teacher shows us activities that I can use to continue my study of a topic.	IR	1. My teacher's methods of teaching with diagrams keep me interested in science. 2. My teacher provides opportunities for me to draw diagrams expressing my point of view. 3. My teacher uses different kinds of diagrams to help me understand biology concepts. 4. My teacher's teaching methods make me think hard about a particular diagram. 5. My teacher uses a variety of diagrams when we study different biology topics. 6. My teacher's use of a variety of diagrams enables me to have a better understanding of a certain biological concept.
RR	9. My teacher uses familiar examples to explain scientific concepts. 10. My teacher uses appropriate diagrams and graphs to explain science concepts. 11. My teacher uses demonstrations to show science concepts. 12. My teacher uses real objects to help me understand science concepts. 13. My teacher uses stories to explain science ideas. 14. My teacher uses analogies with which I am familiar to help me understand science concepts. 15. My teacher uses familiar events to describe scientific concepts.	RR	7. My teacher uses diagrams that are familiar to me to explain biology concepts. 8. My teacher uses a wide variety of visuals (pictures, graphs and charts) to explain biology concepts. 9. My teacher uses models to help me understand biology diagrams. 10. My teacher shows how the written text helps explain a biology diagram. 11. My teacher shows how the diagram explains the written text. 12. My teacher uses analogies with which I am familiar to help me understand a particular diagram.

<p>SMK</p> <p>16. My teacher knows the content (s)he is teaching. 17. My teacher knows how science theories or principles have been developed. 18. My teacher knows the answers to questions that we ask about science concepts. 19. My teacher knows how science is related to technology. 20. My teacher knows the history behind science discoveries. 21. My teacher explains the impact of science on society.</p>	<p>AR</p> <p>1. My teacher's tests evaluate my understanding of diagrams of a biology topic. 2. My teacher's questions evaluate my understanding of diagrams while the teaching is in progress. 3. My teacher uses different approaches (questions, models, etc) to find out whether I understand the meaning of a diagram. 4. My teacher assesses the extent to which I understand a diagram. 5. My teacher's tests allow him/her to check my understanding of diagrams. 6. My teacher adjusts the teaching strategy with diagrams in response to the feedback of our learning of concepts.</p>
<p>KUS</p> <p>22. My teacher's tests evaluate my understanding of a topic. 23. My teacher's questions evaluate my understanding of a topic. 24. My teacher's assessment methods evaluate my understanding. 25. My teacher uses different approaches (questions, discussion, etc.) to find out whether I understand. 26. My teacher assesses the extent to which I understand the topic. 27. My teacher uses tests to check that I understand what I have learned. 28. My teacher's tests allow me to check my understanding of concepts.</p>	<p>CR</p> <p>7. Diagrams can be confusing when there is too much abstract information. 8. The process of going from less abstract diagrams to more abstract diagrams suits my learning better. 9. Diagrams are made up of a certain amount of detail, which requires special skills to interpret. 10. Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn. 11. The biology concepts shown in a diagram can be static or kinetic. 12. When I can explain a biology concept with different types of diagrams, I feel more confident about my learning.</p>

Development Phase 3

Once the items within each scale had been written, the opinions of several science education researchers and three experienced biology teachers were sought in order to assess comprehensibility, suitability, and accuracy of items under each scale. After the discussion and review process, some inappropriate items for this study were removed or replaced with new ones that better described the teachers' teaching practice with diagrams. The language expression of items was modified so as to make sure the intention of items can be accurately and completely conveyed to students. The length of some items was adjusted, and the wordings made easier for secondary students to understand. In the end, six items within each category, and 24 items in total remained in the instrument.

Development Phase 4

Subsequently the questionnaires were administered to 215 students in Years 9 and 10 from four teachers' classes in one senior high school in Western Australia. Students' participation was on a voluntary basis. After collecting the data, descriptive statistics, exploratory factor analysis and internal consistency reliability analysis using the Statistical Package for Social Scientists (SPSS) version 18 were obtained.

6.3 VALIDITY OF THE INSTRUMENT

The validity of the instrument was confirmed in terms of its content and construct validity. Content validity refers to the degree that the instrument covers the content that it is supposed to measure (Yaghmale, 2009). In this regard, the content validity was based on observations of teaching and discussions with experienced biology teachers during the process of designing the instrument. The researcher spent seven consecutive months observing biology teachers' daily teaching and these observations provided the first-hand insight into knowing each individual teacher's teaching practice and students' behaviour (see chapter 5). Moreover, reference was made to research on teachers' pedagogical content knowledge and features of visual teaching and learning.

The items in the instrument were cross-checked by several experienced science teachers and science educators to ascertain the content of the scales. Though the teachers and other scholars beared no negative opinions about the items contained in the instrument as a whole, they suggested the items should be easy to comprehend by for secondary students. According to their feedback, the revision of items has been undertaken in many aspects: 1) removing any negatively worded statements to eliminate unnecessary confusion (Barnette, 2000), although it has been determined that negative items have a certain role in ensuring that students responded to questions with full awareness; 2) simplifying items that were ambiguously represent the succinct constructs in the scales; 3) rephrasing and making sentences much clear and concise. Taken together, the major wordings adaptations were made to ensure the statements are less academic and more comprehensible to secondary students. See the original items in Table 6.1.

Findings from the content validity contributed to supporting the construct validity of the instrument. According to Arthur, Day and Woehr (2008), construct validity pertains to the assessment of whether a test is measuring what it purports to measure, how well it does so, and the appropriateness of inferences that are drawn from the test's result and this is usually depending on factor analysis (Anastasi, 1988).

6.4 FACTOR ANALYSIS

Conducting the factor analysis using a varimax rotation showed that the four original scales in the questionnaire were not supported. After removing four items that did not fit into a single scale, therefore twenty items remained. Table 6.2 shows the 20 items used in the survey.

Table 6.2 Items in the Survey with Four Items Removed

Assessing students' perceptions of biology teachers' diagrammatic usage (SPOBTDU)	Adjustments
<p>1. My teacher's methods of teaching with diagrams keep me interested in science.</p> <p>2. My teacher provides opportunities for me to draw diagrams expressing my point of view.</p> <p>3. My teacher uses different kinds of diagrams to help me understand biology concepts.</p> <p>4. My teacher's teaching methods make me think hard about a particular diagram.</p> <p>5. My teacher uses a variety of diagrams when we study different biology topics.</p> <p>6. My teacher's use of a variety of diagrams enables me to have a better understanding of a certain biological concept.</p> <p>7. My teacher uses diagrams that are familiar to me to explain biology concepts.</p> <p>8. My teacher uses a wide variety of visuals (pictures, graphs and charts) to explain biology concepts.</p> <p>9. My teacher uses models to help me understand biology diagrams.</p> <p>10. My teacher shows how the written text helps explain a biology diagram.</p> <p>11. My teacher shows how the diagram explains the written text.</p> <p>12. My teacher uses analogies with which I am familiar to help me understand a particular diagram.</p> <p>13. My teacher's tests evaluate my understanding of diagrams of a biology topic.</p> <p>14. My teacher's questions evaluate my understanding of diagrams while the teaching is in progress.</p> <p>15. My teacher uses different approaches (questions, models, etc) to find out whether I understand the meaning of a diagram.</p> <p>16. My teacher assesses the extent to which I understand a diagram.</p> <p>17. My teacher's tests allow him/her to check my understanding of diagrams.</p> <p>18. My teacher adjusts the teaching strategy with diagrams in response to the feedback of our learning of concepts.</p> <p>19. Diagrams can be confusing when there is too much abstract information.</p> <p>20. The process of going from less abstract diagrams to more abstract diagrams suits my learning better.</p> <p>21. Diagrams are made up of a certain amount of detail, which requires special skills to interpret.</p> <p>22. Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn.</p> <p>23. The biology concepts shown in a diagram can be static or kinetic.</p> <p>24. When I can explain a biology concept with different types of diagrams, I feel more confident about my learning.</p>	<p>Removed</p> <p>Removed</p> <p>Removed</p> <p>Removed</p>

The researcher conducted factor analysis using a varimax rotation, three distinct scales were identified in the instrument renamed as Instruction with Diagrams, Assessment with Diagrams and Students' Diagrammatic Competency (see Table 6.3).

Factor loadings indicate how strongly each item is related to a particular factor, eigenvalues show the relative importance of each factor, and the cumulative variance can be used to check whether a sufficient number of factors have been retained (Field, 2009). The four items removed are: 'My teacher uses a wide variety of visuals (pictures, graphs and charts) to explain biology concepts.', 'My teacher uses different approaches (questions, models, etc.) to find out whether I understand the meaning of a diagram.', 'My teacher adjusts the teaching strategy with diagrams in response to the feedback of our learning of concepts', and 'Diagrams can be confusing when there is too much abstract information.'

In the end, principal component analysis of the remaining 20 items extracted the three succinct sets of factors of Instruction with Diagrams, Assessment with Diagrams and Students' Diagrammatic Competency. The results indicate that the eigenvalue for each factor was greater than 1 as recommended by Kaiser (1960), whilst the cumulative variance for all three factors was high at 51.5% (Table 6.3). Furthermore, all items loaded above 0.40 (with the lowest being 0.46) on their respective factor and did not load on any other factor. Therefore, all of the 20 items were retained.

The Cronbach alpha coefficient was calculated for each factor to provide an indication of the internal consistency reliability. The results portrayed in Table 6.2 show that the Cronbach alpha coefficient for the three factors are 0.90, 0.87, and 0.65, respectively. The factor loadings therefore suggesting the reliability of the three constructs identified in Phase one.

Table 6.3 Factor Loadings, Eigenvalues, and Percentage Of Variance for the *Students' Perceptions on Teachers' Use of Biology Diagrams* Instrument in This Study (n = 215)

Factor loading				
Item No	Original Item No	Instruction with Diagrams	Assessment with Diagrams	Student Diagrammatic Competence
1	1	0.61		
2	2	0.50		
3	3	0.74		
4	4	0.61		
5	5	0.69		
6	6	0.72		
7	7	0.66		
8	10	0.46		
9	11	0.55		
10	12	0.64		
11	13		0.71	
12	14		0.65	
13	16		0.63	
14	17		0.64	
15	9		0.60	
16	23			0.67
17	20			0.63
18	24			0.62
19	21			0.51
20	22			0.50
Eigenvalue		9.05	1.50	1.29
% Variance		39.36	6.54	5.60
Cumulative % variance		39.36	45.9	51.5

Factor loadings less than 0.4 have been omitted from the table. Principal axis factoring with varimax rotation and Kaiser Normalization was used.

6.4.1 DIAGRAMS AS INSTRUCTIONAL TOOLS

Diagrams depict the way things are (or are hypothesized to be) and in part because they are important tools for learning and reasoning about (as well as communicating) structures, processes, and relationships (Whitley et al., 2006). The scale ‘Instruction with Diagrams’ explored how scientific diagrams are employed as an instructional tool in facilitating students’ learning of biology concepts. Ten items from the former Instructional category and Representational category were grouped into this scale; these are items 1 through 10 (See Table 6.3). Examples of items from this scale are: “My teacher uses a variety of diagrams when we study different biology topics” (item 3), “My teacher uses diagrams that are familiar to me to explain biology concepts” (item 4), and “My teacher’s teaching methods make me think hard about a particular diagram” (item 6). The factor loadings of ‘Instruction with Diagrams’ ranged from 0.46 to 0.74. The Cronbach alpha value for this scale was 0.90, indicating that items were a reliable measure of the categories of teachers’ instructional use of diagrams (see Table 6.4).

6.4.2 DIAGRAMS AS ASSESSMENT TOOLS

The scale ‘Assessment with Diagrams’ refers to how the diagrams were used to evaluate students’ learning of biology concepts. Novick (2006) argued that children should learn how to create and use diagrams to model scientific phenomena in the world and to communicate the ideas underlying those phenomena. For example, Catley et al. (2005) proposed to incorporate the diagrammatic reasoning into the learning about evolutionary relationships among species. This scale contains five items, 11, 12, 13, 14, and 15. The Cronbach alpha value is relatively high, 0.87. Factor loadings of ‘Assessment with Diagrams’ ranged from 0.60 to 0.71 (See figure 6.3). Examples of items in this category include: “My teacher’s questions evaluate my understanding of diagrams while the teaching is in progress” (item 12); “My teacher’s tests evaluate my understanding of diagram of a biology topic” (item 11) and “My teacher’s tests allow him/her to check my understanding of diagrams” (item 13).

6.4.3 DIAGRAMMATIC COMPETENCE

The necessity of learning the requisite conventions to understand and use diagrams is often taken to be a defining feature of learning with such diagrams (Hegarty et al., 1991). Novick (2006) argued that domain-specific knowledge within the area of application of conventions enjoys the additional importance, and thus the scale of diagrammatic competence evaluates the students' understanding about the necessity of specific skills and techniques of interpreting diagrams in order to make sense of biological concepts. The scale 'Students' Diagrammatic Competency' deals with students' perceptions of prerequisite skills and abilities to interpret the biological concepts. Five items forming this scale are item 16 through 20 with a reliability value of 0.65, the lowest of the three scales (see Table 6.3). Factor loading of 'Students' Diagrammatic Competency' ranged from 0.50 to 0.67. Examples of items include: "Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn" (item 20); and "When I can explain a biology concept with different types of diagrams, I feel more confident about my learning" (item 18).

Four items that loaded on two scales have been omitted. For example, one item from the original scale Representational Repertoire, "My teacher uses a wide variety of visuals (pictures, graphs and charts) to explain biology concepts", has loaded on both Instruction with Diagrams (0.43) and Assessment with Diagrams (0.55). However, based on the researcher's observations of diagrammatic usage in teaching activities, diagrams together with other types of visuals were often included in teachers' handouts and students' workbooks that have both of the instruction and assessment features. Consequently, the researcher decided to remove this item, as its ambiguity in the way of questioning may prevent students from interpreting the accurate intention of what has been evaluated and thus may further have affected on the entire reliability of the instrument.

For the same reason, two other items were removed from the original instrument. The item "My teacher uses different approaches (questions, models, etc) to find out whether I understand the meaning of a diagram", which has the factor loadings distributed on both Instruction with Diagrams (0.42) and Assessment with Diagrams (0.70). The other item "My teacher adjusts the teaching strategy with diagrams in

response to the feedback of our learning of concepts” has its factor loadings 0.59 on the scale Instruction with Diagrams and 0.52 on Assessment with Diagrams. Through pondering over the two items, some overlap in meaning seemed to be contained by the above two items for they are both related to the term ‘teaching approaches’ or ‘teaching strategy’. Perhaps these terms might be so similar that they could add difficulty for students to interpret the underlying intentions with subtle difference. Since different instructional approaches can be utilized either in the teaching process or the examining students’ learning outcomes. Therefore, the researcher decided to remove the two closely related items.

The fourth item “Diagrams can be confusing when there is too much abstract information” from original competence scale was also removed, because it is hard for students to define what abstract information is and thus to distinguish the amount of ‘abstract information’ from ‘the concrete information’ contained in a certain graph. The researcher’s classroom observations also indicated that the difficulty of interpreting a graph not only depends on the amount of abstract domain-specific knowledge contained, but also involves readers’ application of the diagrammatic conventions. In consideration of the reasons above, the researcher decided to have this items with logical defects removed.

Table 6.4 Cronbach Alpha Reliability Values and Descriptive Statistics of the Three Scales of *Students' Perceptions on Teachers' Use Of Biology Diagrams*

Scale	N of items	Cronbach's Alpha	Teacher S			Teacher D			Teacher C			Teacher B		
			N of students	M	SD	N of students	M	SD	N of students	M	SD	N of students	M	SD
Instruction	10	0.90	37	3.10	1.02	31	4.21	0.83	106	3.32	1.1	41	3.8	0.78
Assessment	5	0.87	37	3.2	1.05	31	4.14	0.81	106	3.25	1.04	41	3.74	0.75
Competence	5	0.65	37	3.33	0.90	31	3.86	0.87	106	3.49	0.83	41	3.57	0.83

6.5 STUDENTS' PERCEPTIONS OF TEACHERS' DIAGRAMMATIC USAGE

Students from four biology teachers' classes answered the questionnaire, and the results indicated that students hold different opinions toward their teachers' methods of integrating diagrams with their everyday biology teaching. The four biology teachers are referred to as Teacher S, Teacher D, Teacher C, and Teacher B. All of the teachers were willing to have the researcher observe them and their students for a period of time and they taught in their normal style despite the presence of the researcher in their classroom. While the numbers of students varied in the four teachers' classes ranging from grade 9 to 11, the researcher did not consider that the number of students would influence unduly the nature of the diagrammatic teaching in explaining biological topics. Hence, the low student numbers was not considered to be detrimental to the study. The students completed the questionnaires on the voluntary basis as well.

Student responses showed the implications that:

- (1) The overall response to this questionnaire was very positive. The mean scores, as shown in Table 6.4, appear to be higher than 3.0, which marked as 'Not Sure' (see Appendix 2). It can therefore be assume that students did not have a negative attitude towards their teachers' teaching and diagrammatic usage in general.
- (2) Students from Teacher D and Teacher B's classes held higher degree of acceptance about their teachers' diagrammatic usage. In general, teacher D and Teacher B scored higher than Teacher S and Teacher C in the three scales as revealed in table 6.4. In the scale *Instruction*, the mean of Teacher D is 4.21, which suggests that students were more than 'agree' with the diagrams and the instructional methods been involved in his lessons. Teacher D scored 4.14 in the scale *Assessment*, which means students 'agree' with the methods he used in examining students' learning outcomes. Teacher B scored 3.57 in the scale *Competence*, higher than the means of Teacher S (3.33) and Teacher C (3.49).
- (3) Teacher D has the highest scores for the three scales (*Instruction*, *Assessment* and *Competence*), while Teacher S has the lowest mean scores. Compared to other teachers, Teacher S's mean are 3.10, 3.20 and 3.33 for

the scales Instruction, Assessment and Competence, respectively. This result corroborates the previous findings of classroom observations conducted in the four participant teachers. Teacher D is an experienced teacher, who has taught biology for more than 20 years. He was awarded a national award for his teaching. Teacher D had used many approaches on helping students visualize the biological concepts, such as PowerPoint slides, overhead projector, models and etc. However, Teacher S was a relief teacher who was temporarily employed and thus may not be quite motivated in his teaching. Meanwhile, his students were not high achievers and every lesson the teacher needed to spend quite a large amount of time in maintaining the discipline in the classroom.

6.6 SUMMARY AND RESPONSE TO RESEARCH QUESTION

The results of the administering the questionnaire in this section answer Research Question 5: “What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?” and the Research Question 6: “How are students’ perceptions of teachers’ instructional strategies with diagrams?”

The three major scales identified by the instrument suggest that biology teachers need to consider a number of issues when diagrams are integrated in in the teaching: Instruction with Diagrams, Assessment with Diagrams, and Student Diagrammatic Competence. The three salient features were found to be major pedagogical functions that diagrams could have during the process of secondary biological teaching. Overall the majority of students answering the questionnaire displayed an acceptable attitude toward their teachers’ instructional methods, with the mean ranging from *3.10* to *4.21* (see table 6.4). However, students’ perceptions differed to that of teachers’ diagrams usage in term of various diagram types and how they used diagram in teaching.

The questionnaire data and the findings from the classroom observations indicated that most participant students recognised teachers’ instructional methods in teaching diagrammatic representations, as being explanatory tools, in representing biological expertise and in help assessing students learning.

Students' perceptions of teachers' instructional use of diagrams differed to the specific instructional techniques used. Meanwhile, students' diagrammatic competency may also serve as an indicator to which teachers need to refer. The data showed that generally by paying attention to the three dimensions mentioned above, it is likely that a better understanding of students' perceptions of biology teachers' teaching performance with diagrams will be achieved. The results also indicated that secondary students have a fair amount of general recognition about the diagrammatic conventions concerning linking relations between the diagrammatic representation and the domain-specific knowledge been embedded.

CHAPTER 7

STUDENTS' UNDERSTANDING OF BIOLOGY CONCEPTS BY RELATING DIAGRAM AND TEXT

7.0 CHAPTER OUTLINE

The previous chapter described the process of evaluating students' perceptions on teachers' use of diagrams in the classroom teaching. This chapter describes an interpretive research study to ascertain how and why diagrams were used in the teaching and learning biology. The purpose of this chapter was to determine the cognitive relationship between students' interpretation of diagrams together with their counterpart – text – when learning different biology topics. In this way, the findings should be more readily transferable to other representational biology learning settings.

This chapter reports the fourth phase of the research program. Objective four describes the investigation of research question 7: What roles do diagrams and text play when learners relate both representations to understand biological concepts? This research intended to find out the cognitive process of individuals' interpretation of biology concepts by correlating both diagram and text, and addresses how representational modes may be related to each other in conveying meaning.

7.1 INTRODUCTION

The researcher chose several biology topics that were part of the students' biology curriculum, and used his knowledge of the research literature and the understanding of the theoretical framework from the previous research findings, to create an interview protocol to track students' understanding switching between diagram and text while learning the biology content. From this background, the investigating process required several iterations, which are broadly described as the follows:

Phase 1: to investigate the understanding by reading the diagram.

Phase 2: to retrieve the interpretation through reading the text.

Phase 3: to compare the information from the both representations and analyze how the representations relate to each other.

Though the general interviewing procedure follows the three phases mentioned above, the questions that students were required to answer varies slightly when the individual interview item was conducted. The purpose of the interviews was to analyse the data about the learners' opinions and experiences with learning biological concepts with diagrams and text.

7.1.1 INTERVIEW PROTOCOL

In order to highlight the distinct functional use of representations, the researcher developed an interview protocol that consists of three items. The three independent items explained three different biological concepts (Predator and Prey, Factors Affecting Photosynthetic Rate, and Kidney Function) with diagrammatical representations (Iconic, schematic diagrams, and charts & graphs) together with textual representations (such as written text, and chemical equilibrium). Some recently taught biological contents were used to compose the interview protocol because the students might have better understanding about the domain knowledge. Although interview participants were familiar with the biological concepts selected in the protocol, all the diagrams and text were developed by the researcher himself so as to prevent students from reciting the answers that they have already known. The interview questions (see Appendix 3) included: debriefing the biological content knowledge they have learnt from the diagram and text, their preferences in choosing representation types, and how the interpretations from different sources correlate with each other.

7.1.2 STUDENT INTERVIEWEE SAMPLE

Interviewing participants was the major method of data collection in this study. A total of 11 students from grades 10 and 11 in one local secondary high school participated in the interview; 9 students were from grade 10 and 2 from grade 11

and their participation was on a voluntary basis. Approximately 30 minutes was needed for each interviewee and each interview participant needed to answer the questions from the three different interview protocols. The interviewing data were vital in probing students' conceptual processes while learning biology concepts with diagrams and text.

Graphs, diagrams, and the written text are designed to make visualizations of phenomena easy to see and experience in the classroom settings. Every mode of representation is designed for different, but equally important educational reasons. Therefore the use of multiple external representations can help learners come to understand complex scientific concepts. However, one thing in common, each mode of representation has particular advantages and disadvantages in conveying scientific information. The purpose of investigating the information that has been extracted from the diagram is to identify the advantages and disadvantages that apply to this frequently used visual representation type. The distinct representational attributes that can be used in learning thus deserve some special attention, before reviewing the complexity of the correlations between multiple representations.

7.1.3 CODING AND INTERPRETIVE ANALYSIS

Diagrams and text were presented to the respondents without mentioning the answer categories, so students were expected to state their interpretation of both representations in their own words. The audio-taped students' responses were transcribed and the transcripts were read through many times by the researcher, looking for commonalities and anomalies in the data. The qualitative data were coded in terms of relevant aspects of students' understanding and activity (Silverman, 2000). Categories were created in tabular form to correspond to the analysis of the data in light of the educational functions applied to the multiple representations learning environment. As categories were created and coding continued, the performance of each representation mode was assessed, resulting in learning effects brought by the combination of the representations. After the coding of all students' responses was complete for a particular question or a single procedure in the multiple representational learning, the coded data for

each category was inspected and the frequency of the coding was assessed. To improve the inter-rater reliability, the researcher's supervisor and another science education researcher examined the interview protocol and the categories generated from students' response.

The foundation of the interpretive analysis throughout this study is Ainsworth's (1999, 2006, 2008a) conceptual framework for considering learning with multiple representations. An interpretive design (Erickson, 1986) was addressed to this interest. For the generation of findings and conclusions, the transcribed data were checked many times to ensure accurate coding and the description of individual's learning process. Since the research makes use of constructivist perspective, assuming that each individual constructs his or her own understanding with diagram and text engaged in the learning.

7.2 PREDATOR AND PREY RELATIONSHIP

In item one of the interview protocols – predator and prey relations, the predator and prey population changes were displayed as two curves on a line chart. Students need to distinguish the two fluctuating curves representing predator and prey between x-axis and y-axis of the chart (See figure 7.1), and then to figure out their changing pattern. Later, students were asked to read a short paragraph depicting the same content information about predator and prey populations. Students' learning outcome could therefore be analyzed relating to their preferred representation type(s) and the interpretation.

Population dynamics – predator and prey relations

Diagram

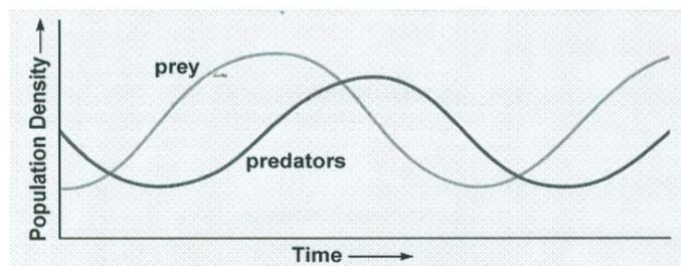


Figure 7.1 Diagram used in constraining function

7.2.1 EXTRACTING THE INTERPRETATION OF DIAGRAM

Students' responses suggest what particular conceptions they have explain by learning with the diagram. The researcher placed particular attention on the relationship between the diagram and text through the comparison between students' learning from the two representations, respectively.

The interview questions (see Appendix 3) start by requesting students to explain the specific biology concepts in the diagram. Students' different conceptions retrieved from interpretation of the diagram in the interview item – predator and prey are shown in Table 7.1. The results show 27.27% of the interview participants (PPD1) were able to give complete and correct answers; 54.55% of the participants' response (PPD2) grasped the main point of the biology topic, though their answer was not as complete to some extent. The difference between PPD1 and PPD2 was whether or not the student could identify that the predator and prey relation is a repetitive cycle. Only 18.18% of participants (PPD3) gave an incomplete answer. In general, participant responses indicated that most of the students (PPD1 and PPD2 81.82% in total) can identify the key conceptions suggested by the diagram.

Table 7.1 Coding for Students' Responses of The Meaning by Learning the Diagram in Interview Item – Predator and Prey (n=11)

Code	Explanation	Number (Percentage)
PPD1	The peak of the predator population occurs after the peak of the prey population because there is initially more prey to feed on. As the predators consume more prey, the prey population decreases and the predator population decreases with it. The whole cycle is then repeated.	3 (27.27%)
PPD2	The peak of the predator population occurs after the peak of the prey population because there is initially more prey to feed on. As the predators consume more prey, the prey population decreases and the predator population decreases with it.	6 (54.55%)
PPD3	The peak of the predator population occurs after the peak of the prey population because there is initially more prey to feed on.	2 (18.18%)

Students classified as having a complete understanding:

Interviewer: Please describe the biological concepts suggested by the diagram.

Student 3: This diagram describes the population of the prey and the predator. When the population of the prey peaks, the predators' population starts to grow, because there is more prey to feed on as the predators consume more prey, the prey population drops and the predator drops with it. But the peak of the predator population is after the peak of the prey population, so ...

Interviewer: Okay, Can you describe more details about this diagram, from the very beginning?

Student 3: The prey population is at a low, because the predator population is medium, but as the predator population drops, the prey population rises, because there are less predators to feed on them and so the prey population peaks; the predator population also starts to rise, because there is more prey to feed on. And as the predator once again feed on more prey, the prey population will drop, the predator population rises and the whole cycle begins again.

Another student's response shows that a complete and accurate understanding about this biological concept has been achieved.

Interviewer: So please discuss the biology concept suggested by the diagram.

Student 5: Okay, so the biology concepts are just – well, this diagram represents the time versus population density for predators and prey of a specific community. So it shows that the prey peak slightly before the predators, so this was suggested – okay, obviously there are more preys than the predators at most given times. When the prey is actually less than the predators, both populations tend to decrease. Yeah, so both groups have similar growth patterns. It's just that the predators are slightly underneath, slightly further away, so this would suggest that the predators often need the prey and it takes longer for them to reproduce through the same patterns.

Interviewer: Explain this diagram from the very beginning, from the very left side.

Student 5: Okay, so at this point, there are more predators than prey, so the predators would eat the prey, and then, because there's less prey, a lot of the predators would die, which would cause a decrease. And because there's a decrease in predators, there will be an increase in prey. So whilst this is occurring, the prey would increase. As the prey is increasing, there will be more food for the predators, which means they can reproduce more. As the prey peaks, the predators will have the maximum amount of nourishment possible, and it will take longer for that digestion, which is why there's a slight delay in the peak of the predators. So as the predator's peak, because they're eating the prey, the prey will decrease at this time and then the same cycle will continue.

The knowledge that **student 3** has learnt from diagram are:

1) The predator and prey relationship over the two variables – population density and time: “the peak of the predator population is after the peak of the prey population (student 3)”, **2)** The reasons behind: “because it has more prey to feed on and as the predators consume more the prey, the prey population drops and the predator drops with it (student 3)”, **3)** The developing pattern: “...and the whole cycle begins again (student 3)”. It seemed that student 3 tended to be able to summarize most of the knowledge points from the diagram, as he recognized the predator and prey relationship is an endless cycle.

Student 5 also summarized three points by reading the diagram and his answer was:

1) The relationship between population density and time: “....the predators would eat the prey (student 5)”. **2)** The reasons behind: “And because there’s a decrease in predators, there will be an increase in prey. So whilst this is occurring, the prey would increase (student 5)”. **3)** The developing pattern: “the prey peak slightly before the predators (student 5)”; “....and then the same cycle will continue (student 5)”.

It is also worth seeing some other responses from students who were not able to detect as much information as those two students above.

Interviewer: Now, please describe the biological concepts suggested by the diagram.

Student 1: I think it would mean that, once the prey’s number is getting high ... gets too high, the predator’s number.. or population grows high as well. And once the predator’s number grow high, they eat prey, they hunt down the prey, the prey’s number goes down. Therefore predators don’t have enough food, and the number goes down as well.

Students classified as not having a non-complete understanding

While PPD2 category contains most of the content knowledge, student responses under this category failed to recognize that the developing pattern of predator and prey is a repetitive cycle. From the responses of the two participants, they all indicated the major concepts shown by the diagram. In particular, the major content knowledge that student 1 identified are as follow: **1)** The relationship between the two variables (population density and time): “once the prey’s number is getting high ..., the predator’s number or population grows high as well. And once the

predator's number grow high, ... the prey's number goes down (student 1).” 2) The reasons behind: “ .. they (predators) eat prey, they hunt down the prey..(student 1)”.

Another two student's responses indicated that the 'repetitive cycle' has not been achieved:

Interviewer: My question is, please describe the biological concept suggested by the diagram?

Student 7: It's the relationship between the population density and time, over time.

Interviewer: Can you describe the specific information from the very beginning?

Student 7: What's showing as the prey increasing. The predators increase and as, so they have a direct relationship.

Interviewer: And then what happened next? Maybe this part of the diagram...

Student 7: Well as the amount of prey decreases, the predators also decrease.

Interviewer: Do you know, what are the reasons that cause the decreasing of the prey?

Student 7: Because for the predators to survive they need the prey and well as the prey increases there are more predators to feed on them.

Interviewer: Are there any external factors?

Student 7: Well I guess things like the weather as well, the like external environment yeah.

Interviewer: Did the diagram tell you that?

Student 7: No.

Student 7 has been classified under the category PPD2, and his major points can also be summarized by scrutinizing the transcript. 1) The relationship between variables: “Because for the predators to survive they need the prey and well as the prey increases there are more predators to feed on them (student 7)”; 2) The reasons behind: “as the prey increasing. The predators increase Well as the amount of prey decreases, the predators also decrease (student 7)”.

It is worth seeing another student's answer, which was even limited and in general.

Interviewer: My first question is, please describe the biology concept suggested in this diagram.

Student 9: Okay. So the prey and predators they kind of coincide with each other. And the prey raises the predator also rises. It's kind of like follows each other, just of like a delay in time a bit.

Interviewer: So can you describe this diagram from the very left side?

Student 9: The prey starts off being higher than predators, then after a while they meet, so they're about the same amount, and then prey rises followed by predator.

Student 9's response was rather limited and simple. Student 9 confined his answer only to **1)** The relationship between variables: "And the prey raises the predator also rises. It's kind of like follows each other, just of like a delay in time a bit (student 9)". There is no other meaning can be interpreted except the point shown above.

In summary, students have different levels of interpretation about the single diagram presented to them. Some provided in-depth understandings, while other interviewees' learning was relatively limited. The first two students (students 3 and 5) showed that they have developed a thoughtful understanding; though students 1 and 7 collected relatively less amount of information than their peers, they did not omit the major content shown by the diagram. However the last student's understanding was superficial and did not provide enough explanations in biology to show his understanding of the topic.

The next section tracks these five students' performance in learning with the other representation type – the text.

7.2.2 EXTRACTING INFORMATION FROM THE TEXT

Phase two of the interview procedure required the interviewer to investigate what specific information students can gain by reading the other mode of representation – text. After students had completed their interpretations of diagram, they were presented with the main text associated with the diagram. The text constitutes another mode of semiotic representation that students can draw on to make sense of the biology topic. Textual representation has been placed at the end of the continuum, which indicates that the amount of contextual information is more abstract and has less detail (Pozzer-Ardenghi & Roth, 2005). With more abstraction contained within the textual representation, the text depicts information that is presented in a less concrete, visual-friendly way. In this case, learners are asked to identify the information contained by a different form of representation that may or may not be their preferred representational type. Thus, it is worth trying to see how well students

can learn with another type of representation in the multiple representations environment.

In the interview protocol, students were presented with a paragraph that depicts the predator and prey relation in the form of written text (see figure 7.2).

Text

What actually happens in nature is that a cycle develops where at some time the prey may be abundant and the predators few. When the number of predators is scarce the number of prey should rise. As the number of predators rises, the number of prey decline. Because of the population density of prey, the predator population grows and reduces at regular intervals according to the fluctuation of population of prey. Therefore, the predator oscillations always lag behind the prey oscillations.

Figure 7.2. Text used in the constraining function

Students were given some time to read the paragraph, and then asked to answer the interviewer's question "what you have learnt from the text?"

As a result, the outcome shows that students' responses can be classified into two categories: PPT1 that covers the most complete understanding, which includes the relationship between variables, the reasons behind and the developing pattern. PPT2 has concluded only two major points the relationship between variables and the reasons behind that relationship. See the summary Table 7.2.

Table 7.2 Summary of Students' Responses to Textual Representation about 'Predator and Prey'

Code	Explanation	Number (Percentage)
PPT1	The population of predator always depends on the population of the prey. The predators always lag behind the prey. When there are less predators, the prey number rise; the increase of prey will cause predators to rise. The cycle is then repeated.	8 (72.73%)
PPT2	The population of predator always depends on the population of the prey. The predators always lag behind the prey. When there are less predators, the prey number rise; the increase of prey will cause predators to rise.	3 (27.27%)

Less visual friendly as the text is, students tended to interpret the paragraph discussing the predator and prey relation word by word. Eight out of 11 students could give a complete and correct answer towards the meaning contained in the text (coded as PPT1). In particular, the response from students 3 and 1 are:

Interviewer: Now, have a look at the text. Yep, please describe, in detail, what the paragraph is about.

Student 3: It's speaking ... talking about the picture, the diagram, and it says basically the same thing. It's about the predator population rises and drops.

Interviewer: Keep going.

Student 3: Okay, it's the same thing as the diagram, it just ... yeah, it describes it further.

Interviewer: Just describe the information in detail, please.

Student 3: It's talking about how the cycle of prey and predators – how the predator population goes up and the population goes down when there are more – how it declines when there are more predators and how prey will rise when there is a decline in predators.

Student 3 can also be classified under the PPT1 – the complete type of responses. As she pointed the 1) The relationship between variables: “It's about the predator population rises and drops it's the same thing as the diagram (student 3).” 2) The reasons: Though student 3 did not repeat her understanding to explain the phenomena that why population fluctuates, she mentioned “the predator once again feed on prey – (PPD1 - student 3)” as she described her understanding about the diagram. Therefore, the researcher assumes that she had this information from the textual representation for the moment. 3) The developing pattern: “....the cycle of prey and predators.... the predator population goes up and the population goes down (student 3)”.

Student 1's answer also indicated his ability to draw complete information from the text:

Interviewer: Now have a look at the paragraph. Please tell me in detail, what does this paragraph tell you?

Student 1: What it means is ... when there is less predators, the prey number will rise. The prey number rises, the predator number rises as well, because there is more food. But when the predators rise, the prey number drops. And the prey number drop, the predator number drops. And the cycle starts again.

The students' interpretation of text can be summarized as: **1)** The relationship between variables: "when the predators rise, the prey number drops. And the prey number drop, the predator number drops (student 1)." **2)** The reasons behind: "the predator number rises ...because there is more food (prey) (student 1)." **3)** The developing pattern: "And the cycle starts again (student 1)".

The evidence shows that both student 3 and student 1 performed very well in interpreting the information by reading the textual representation. They all extracted three points as listed above: 1) the relationship between variables, 2) the reasons behind their choice and 3) the developing a pattern. In addition, more evidence suggests that some performances have been found in student 3 and student 5, as they began to ponder the linkage of information between the diagram and text. "It's speaking ... talking about the picture, the diagram, and it says basically the same thing (student 3)." "The paragraph is basically an interpretation of this graph (student 1)." Though they have successfully realized the similar information been contained by the two distinct representations, the researcher sought their opinions later on how the two representations correlate each other in facilitating the learning.

Three interview participants' answers were not as complete as their peers because they missed the information that the predator and prey is a repetitive cycle. Their responses have therefore been coded as PPT2 as shown in the Table 7.2.

The exemplar responses can be found in student 5:

Interviewer: so please describe, in detail, what the paragraph is about.

Student 5: The paragraph is basically an interpretation of this graph. it's basically saying that the predator relies on the prey, so when there are more prey, there are less predators, and this causes the level of prey to rise, as there are less predators, prey rises, it causes predators to rise. As a result, since the predators rely on the prey, the prey would decrease as the predators increase. And this is why this happens at the specific times and because the predators actually rely on the initial movements by the – the initial growth of the prey, the predators always lag behind in the peaks, because there's no way they can achieve the peak before the prey, because of the fact that they actually need the prey to survive.

There are three points can be drawn from student 5's answer: **1)** The relationship between variables: "when there are more prey, there are less predators, ... (when) there are less predators, prey rises. The predators always lag behind in the peaks, there's no way they (predators) can achieve the peak before the prey (student 5)." **2)**

The reasons behind: “it’s basically saying that the predator relies on the prey (student 5).” However, though the detailed and reasonable answer was given by student 5, he did not show his recognition on predator and prey population changing cycle.

7.2.3 INDIVIDUAL PREFERENCE FOR A REPRESENTATIONAL TYPE

Multiple representations theory suggested that when more than one representation is engaged, learners may turn to different types of representations to understand the concept (Ainsworth, 1999). Usually, the learners may refer to the more familiar representation type so as to make sense of the more complicated one. In this phase, the researcher therefore would like to find out whether the diagram or the text is more favored by students and how this familiarity contributes to individual learning.

Table 7.3 Coding for the individual Preferences of Representations (n=11).

Preferences	Reasons	Number (Percentage)
Preference for diagram	Easier to understand	2 (18.2%)
Preference for text	Informative; straightforward and is easier to interpret	9 (81.8%)

Students who missed the idea of cycle in the diagram were not exactly the same ones who also missed this idea when reading the text. By posing the question “which of the two, the diagram or the text, helps you understand the biological concept better?” during the interviews, the researcher sought all interview participants’ opinions towards the usefulness of the representations in contributing to their overall understanding of the biology concept. As shown in the Table 7.3, 81.8% of the participants considered the text facilitated their learning better than the diagram. Their reasons for choosing the text over the diagram to learn this concept include: “there could be a lot of explanations to what causes this, I find text is more straightforward and it’s easier to interpret for me (student 5).”; “it sort of tells you directly straight out. You don’t really have to try and work it out yourself, it (text) just tells you (student 6).”; “The text is very simple, it’s not very complicated.... So it’s easier to understand. Sometimes, even though there’s quite a large amount of text (student 4).” For those participants who prefer text to diagram, it is more

obvious that they believe the textual representation provides the information that can be much directly interpreted. They can learn the information directly by reading the written text, without processing and analyzing any visual properties embedded within the line chart.

On the other hand, 18.2% of the interview participants found that the diagram was more useful in figuring out the population changes between predator and prey. This group of students tended to be visual learners, their reasons for choosing to learn with diagram as the preferable representational type are: “The diagram tells you like prey increases but the predator decreases. So you understand that, what’s happening there. And telling you that by time by time that’s what’s happening (student 11)”; “I like seeing visual things, if I read something like this. I can get the same message, but it is much faster for me to pick up the message (student 2).” Unlike other students, students 2 and 11 would prefer to extract information from the diagram. A major reason for this is the extraction of information from visual representation is easier for visual learners.

After knowing students’ personal preferences on choosing either diagrammatic or textual representation, the next section focuses on examining students’ learning outcome so as to identify the roles of diagram and text in learning.

7.2.4 EXAMINING THE LEARNING OUTCOMES

In this phase, the researcher sought students’ opinions on the learning outcomes that they have gained by switching between the two representations. Ainsworth (2006) suggested that when a relative new understanding was constructed, the learning with the more familiar representation would have constrained the learning of the much complicated one. In this case, depending on the individual learner’s personal preference, the interpretation of diagram could constrain the learning of the text, or vice versa. Thus, it is worthwhile investigating whether or not the student is conscious of the improvement of his/her learning.

No matter what representational preferences are, evidence shows that all the 11 interview participants gave a positive answer confirming that their learning has been improved by learning with diagram and text together. They could achieve some

kinds of ‘complete’ or ‘better’ understanding about the biology concept (See table 7.4).

Table 7.4 Coding for the individual’s self-Consciousness of the Learning Outcome (n=11).

Learning outcome improved or not	Number (Percentage)		
	Prefer Text	Prefer Diagram	Total
Positive	9 (81.8%)	2 (18.2%)	11 (100%)
Negative	0	0	0

The students’ responses were recorded and they were also requested to give an example to confirm that a better interpretation had truly been achieved.

Interviewer: Can you develop a better understanding about this topic by reading the diagram and text together?

Student 2: Yeah.

Interviewer: What is your better understanding?

Student 2: I know that the predators lag behind the prey, because the fluctuation of the prey.

Interviewer: You cannot have this information by reading either the diagram or the text?

Student 2: You can have this information but you don’t know why.

Interviewer: So you have your interpretation goes deeper into this topic?

Student 2: Yeah.

Interviewer: Can you give an example about this predator and prey relation in the real world?

Student 2: Let’s see ur... alligator and fish. I am from Bangladesh, during the summer the fish breed more, then the crocodiles come out; but during winter, no.. no, during winter more fish come out, the corridors increase. During winter, the crocodiles die because there is not enough fish. And when the fish grow again, the crocodiles increase.

Student 2 confirmed that he would not have been able to know the reasons “why” that cause the predator and prey population fluctuation until he studied the topic with the combination of diagram and text, though the information can be obtained by interacting with one by one. In other words, student 2 understood the population changing phenomena suggested by the text or diagram individually at first, and then

reached his coherent understanding – why the population curves fluctuate at regular intervals by relating the diagram and text jointly. Based on his newly achieved understanding, he provided an example that follows the predator and prey relation (though alligator and fish may not be predator and prey in nature), his emphasis has been placed on what are the driving forces/causes that motivate the population to rise and fall as well as the internal consistencies between variables, that is, the changes of predator is always decided by the prey. Since the diagram is student 2's preferred representational type, the finding assumed that students who preferred to learn with diagrams could achieve the complete interpretation with the aid of the text.

Here is another example showing students could achieve better understanding by reading the text.

Interviewer: Can you develop a better understanding about this topic by reading the diagram and text together?

Student 1: Yeah. Diagram is sort of visualized; it allows me to initially understand the concept. With what you initially understand, you read the text, you get more in-depth. You can build on the diagram like what the image say in your mind.

Interviewer: Can you give me some examples please. What kind of complete understanding you can have?

Student 1: Maybe fish, like two kinds of fish in the ocean. One kind of fish is feed on the other fish. Because of human fishing industry, the number of fish cause the death of the other fish feeds on, the number has dramatically dropped. So the predator won't have enough food. The number of the fish, which is the prey, does not rise again, because human continuously fish on both of them. So maybe predators won't get enough food, maybe they get extinct or whatever.

Student 1 believed that text helped the construction of information built on the basis of the interpretation of diagram as he stated "You can build on the diagram like what the image say in your mind". This is in line with Ainsworth's definition of constraining interpretation effects between two representations; the familiar or easy

to interpret representation may support learners' understanding of the complicated representation.

Multiple representations can be used in the way that one representation constrains interpretations of another one (Ainsworth, 2006). In particular, one form of representation may be complex to the learner, while the second representation is more familiar or easier to interpret. Thus, the role of the simple representation is to constrain the interpretation of the more complicated representation.

7.2.5 THE CONSTRAINING EFFECTS BETWEEN DIAGRAM AND TEXT

Ainsworth (2006) argued that the constraining function can be achieved by taking advantage of the features of multiple representations: on one hand, learners' familiarity with one representation can constrain the interpretation of the less familiar one; on the other hand, the constraints can be realized by making use of inherent properties of representations. The constraining relation will be examined in which students' interpretation of one representation may be constrained by the other representation, especially when diagram and text are presented together.

The following two examples track the constraining function exerted on the process of student's learning with representations. No matter whether the diagram or the text has been chosen as the preferred representation, constraining effects have been generated.

7.2.5.1 Constraining By Different Internal Properties

Student 2 felt comfortable to figure out the predator and prey relation with the diagram, he responded to interviewer as:

Interviewer: which of the two, diagram or text helps you understand the biology topic better?

Student 2: the diagram.

Interviewer: Why?

Student 2: I like seeing visual things, if I read something like this, ... it is much faster for me to pick up the message.

Meanwhile, evidence also suggests that student 2 extracted more in-depth interpretation from the diagram than from the text. As he mentioned three points from the reading the diagram: **1)** The relationship between variables: “when there are no predators, the prey are in plenty numbers. When the prey has little numbers, the predators start to eat the prey and their number rise (student 2).” **2)** The reasons behind: “When the prey number decline, the predators have no more food, so they declined. Prey start to ascending, because there is no predators (student 2).” **3)** The developing pattern: “And the cycle repeated (student 2)”.

However, only two points were drawn from the text: **1)** The relationship between variables: “the prey is up, the predator is down, ... the predators come up, ... the prey goes down (student 2).” **2)** The reasons behind: “they (predator) start eating the prey (student 2).” Though he picked up the notion that the predator and prey relation repeats itself in a cycle, he did not get this information from reading the text.

The advantage that student 2 obtained by learning with both diagram and text together is that, the learner could have a coherent understanding about why the population of predator always fluctuates according to the changing of the prey.

Interviewer: Can you develop a better understanding by reading the diagram and the text together?

Student 2: Yeah. I know that the predators lag behind the prey, because the fluctuation of the prey.

Though the text could depict the phenomena of population changing between predator and prey, student 2 drew a more accurate conclusion that the changing pattern of the population oscillates. The Student 2 actually knew the reason “why” that caused the phenomena depicted by the two representations.

Interviewer: You cannot have this information by reading either the diagram or the text?

Student 2: You can have this information but you don’t know why.

Interviewer: So you have your interpretation goes deeper into this topic?

Student 2: Yeah.

To conclude, the way that constraining effects happened for student 2 belongs to the constraining by inherent properties of representations (Ainsworth, 2006, p. 188). The rise and fall of the curves in the chart provided the student with more accurate

interpretation about the population changing in the predator and prey relationship. Though the written text gives a verbal narration about biological topic been tested, student 2's understanding of the text evolved by the constraints of the diagram. As previously mentioned, three obvious points can be extracted from student 2's understanding of the diagram, whereas only two points can be drawn from reading the text. All these evidence suggests that student 2's 'coherent understanding' is the result of the constraining effects exerted by the diagrammatic representation over the textual representation. Previous studies have also confirmed that graphical representations are generally more specific than textual representations (Stenning & Oberlander, 1995). The inherent ambiguity contained by the textual expression has been constrained and thus made much accurate by the content information presented pictorially. Therefore, when diagram and text are presented together, interpretation of the text may be constrained by the diagram.

7.2.5.2 Constraining By Learners' Familiarity

There is evidence also showing that individual learner's familiarity of the different representations can play a constraining role in facilitating biology learning when diagram and text are presented together. The much familiar representation can constrain interpretation of a less familiar one (Ainsworth, 2006). Therefore, it is also worthwhile paying attention to investigate the performance of the students who chose text as the preferred representation mode.

Interviewer: Which of the two, the diagram or the text helps you understand the biological concept better?

Student 9: I think it's the text maybe.

Interviewer: Why the text?

Student 9: Because it actually explains what's going on. But when I see the visual one like the diagram, I might not get such a clear picture. So the text helps better.

When the written text was employed alongside with graphic representations such as diagrams, student 9 believed he could have more information from the written text. As he confessed that he may not be able to "get a clear picture" from the diagram, and "the text helps better". Meanwhile, referring to the information he got from

reading the diagram. He tended to have not too much of information: **1)** The relationship between variables: “the prey and predators coincide with each other. When the prey rises, the predator also rises. They follow each other, just like a bit delay in time (student 9). **2)** The reasons behind: “then prey rises followed by predator (student 9)”. As can be seen from his answer, the information obtained is quite limited.

Since the text has been considered as the preferred mode of representation, the student indeed extracted more information from the text than from the diagram. The content information from text includes: **1)** The relationship between variables: “predators basically affected by the prey and most of the time I think they actually affect each other (student 9)”. **2)** The reasons behind: “predators always end up eating up the preys, and predators always are like behind the prey (student 9). **3)** The developing pattern: “the prey rises the predators also rise, and it repeats that (student 9). It is obvious to note that student 9 has acquired more expertise in understanding the predator and prey relationship by reading the text.

Student 9 also confirmed that he could have a better understanding about the biology knowledge if both diagram and text are presented to him together. He found that learning with both representations may provide more advantages than learning with the individual representation either diagram or text. As he said, “when I see the visual one like the diagram, I might not get such a clear picture because I’m not a good visual learner. So it’s (the) text helps better (student 9)”. This statement could imply that: on one hand, the student is not confident in relying solely on a diagram for the conceptual learning; on the other, he found that the text intellectually explains the diagram. Furthermore, more evidence was found on exploring how diagram and text cooperate in delivering the meaning: “I frequently refer to the text that comes in handy. The diagram gives much the overview of topic... it’s more on the text actually in the details (student 9)”. In other words, this student believed that the text gives much detail about the concept, while the diagram synthesizes the information and displays the content knowledge visually. This might be the reason that student 9 found the diagram hard to interpret and therefore the textual representation was more popular than the diagram.

Student 9 admitted that his improved learning has been realized by referring to both diagram and text. Especially the textual representation helped him understand the diagram better. The example he gave to prove his better understanding is about “lion and rabbit”.

Student 9: So if there's like, there are lot of rabbits around then the lions be eating them, and because of that the rabbits will decline. And since there's less food now the lions also decline. And when the lion declines the rabbits start breeding again and it kind of repeats the whole cycle.

The analysis of the above example suggested that student 9's newly achieved complete understanding includes: 1) The relationship between variables: “because of that, the rabbits will decline, and since there's less food now the lions also decline (student 9)”. 2) The reasons behind: “there are lots of rabbits around, then the lions will be eating them... And when the lion declines the rabbits start breeding again (student 9)”. 3) The developing pattern: “it kind of repeats the whole cycle (student 9)”. As can be seen in his answer, student 9 achieved a much fruitful learning outcome than the content knowledge been generated from reading the individual diagram at the very beginning. The newly learnt content knowledge - the developing pattern earlier has been picked up by student through learning with the combination of diagram and text. Ainsworth (1999) asserted that one of the advantages of using Multiple External Representations is the combinations of representations can help learning when one representation such as text constrains the interpretation of a second representation such as diagram. To conclude, the interpretation of the sometimes seen as an ambiguous representation – diagram has been constrained by the specific representation – text. The constraining function by familiarity has been performed through diagrammatic representation and textual representation.

7.3 FACTORS AFFECTING PHOTOSYNTHETIC RATE

For the interview item *Factors Affecting Photosynthetic Rate*, a number of requirements for photosynthesis such as the effect of light intensity, temperature, and carbon dioxide on photosynthetic rate were depicted on several line charts (see chart 7.2). Students need to answer a series of questions about how photosynthesis is affected by the factors mentioned in the above. Later, a textual representation was presented to students and the researcher sought students' interpretation of the

concept that had been suggested by the text. Another form of textual representation was engaged in this item, that is, a chemical equilibrium. In addition, a short paragraph was also provided to assist students' learning. Lastly, students' interpretation from both forms of representations was compared.

7.3.1 EXTRACTING THE INTERPRETATION OF TEXT

In this interview item, students were presented with the textual representation that depicts the process of photosynthesis (see the textual representation in figure 7.3). Students were given a period of time to read the text and then were asked to describe the entire process of photosynthesis. Besides, their comments were sought on the particular advantages (if any) to learn with the textual representation.

Text:

Photosynthesis is of fundamental importance to living things because it converts solar energy into chemical energy stored in molecules, releases oxygen gas as a waste product, and absorbs carbon dioxide. Chlorophylls is used to absorb the light energy.

Photosynthesis is summarized in the chemical equation below:

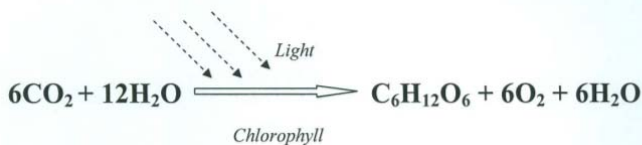


Figure 7.3 Text used in the complementary function

Table 7.5 shows students' interpretation of the text, the result can be classified into two categories: 63.64% of the interview participants' response (PRT1) includes the correct and the most complete answers, in which all factors relevant to photosynthesis have been mentioned by the interviewees. 36.36% of the participant's responses (PRT2) refer to the answers that are correct but not complete. The students who missed one or two participating substances are classified under this category. This result may be explained by the fact that although most students could understand the majority of the photosynthesis process suggested by the textual representation, some others failed to give a complete and detailed description about this biological concept.

Table 7.5 Coding for Students' Responses of The Meaning by Learning the Text in Interview Item - Photosynthetic Rate

Code	Explanation	Number (Percentage)
PRT1	Photosynthesis happens in plants. Plants use chlorophyll to absorb light energy and then using carbon dioxide, water and light, the plants turned all these into chemical energy as waste products, such as glucoses, oxygen, and water.	7 (63.64%)
PRT2	The process of photosynthesis basically converts solar energy into chemical energy and stored in the cells. The products of this process include oxygen and water.	4 (36.36%)

7.3.1.1 Students Classified as Having a Complete Understanding

Seven students could give a correct and complete answer about the content of photosynthesis shown by the text (coded as PRT1). Being correct means that was no alterative conceptions could be found in the student's response. Also being complete refers to the student providing a thorough description about his/her understanding of the biological concept that contained all the terminologies and information been given.

Interviewer: Can you explain the biological knowledge shown by the text?

Student 1: It is in plants. It doesn't say in here, but I know it is in plants. Plants use chlorophyll to absorb light energy and then using carbon dioxide and light, they turned the light energy into chemical energy, they store in the glucoses and they produce oxygen, water as waste products.

Interviewer: What are the factors that can be affecting the photosynthesis rate?

Student 1: the light, the chlorophyll in the plant, water, and any carbon dioxide present in the atmosphere or environment.

The complete and correct interpretation can also be found in student 2's response:

Interviewer: Please explain the process of photosynthesis suggested by the text?

Student 2: The chlorophyll absorbs light, carbon dioxide and water, and transforms them into the glucoses, oxygen and more water.

Interviewer: Which one is glucose? [The glucose was written as $C_6H_{12}O_6$ in the text]

Student 2: So this is glucose.

Interviewer: How do you know that?

Student 2: I do chemistry as well, and that's carbon dioxide, water, oxygen. [Student 2 pointed CO₂, H₂O and O₂ respectively]

Interviewer: Can you explain the photosynthesis from the very beginning?

Student 2: It converts solar energy into chemical energy, in which it stored in the molecules. Then it releases the oxygen as a waste product, and absorbs carbon dioxide.

Interviewer: Any chemical substances participate in this process?

Student 2: Chlorophyll, Carbon dioxide and water.

Interviewer: What do you think are the factors affecting photosynthesis rate?

Student 2: Sun is available, carbon dioxide availability and water.

Student 1 and student 2's responses show that they both have gained scientific understanding about the concept of photosynthesis, that is, solar energy has been transformed into chemical energy. The participating substances are carbon dioxide, water, sun light and chlorophyll. The process produces glucose, oxygen and water. Their responses were considered to be complete because they used all the information in the text to depict their understanding. No chemical substance has been missed out.

However, some students' responses were considered to be less complete, though they did not show any alternative conceptions toward this biological concept. The reasoning from Student 4 and student 10 seems to be less complete, because they did not mention one or some of the substances in their explanations.

Interviewer: Please explain the process of photosynthesis shown by the text?

Student 4: Plants use light energy and then turned the light energy and carbon dioxide into chemical energy, they produce waste products like oxygen and water.

Interviewer: what are the factors that can affect the photosynthesis rate?

Student 4: the light, water, and carbon dioxide in the atmosphere or environment.

7.3.1.2 The Response from Another Student That Has Been Coded as PRT2:

Interviewer: Can you please explain the process of photosynthesis shown by the text?

Student 10: Um, the plant absorbs carbon dioxide from the air and along with the water, with the presence of light and chlorophyll, it can produce glucose and oxygen as a waste product.

Interviewer: So what colour is chlorophyll?

Student 10: Green.

Interviewer: Green. What do you call this? [The researcher pointed at the $C_6H_{12}O_6$ in the equation]

Student 10: Glucose.

Interviewer: Glucose. What is the glucose for?

Student 10: For energy... .. for the plant to grow.

Interviewer: What do you think are the factors that can affect the photosynthetic rate?

Student 10: The light, the temperature, um...

Student 10's response has been classified under the category of PRT2, because she missed one product of the chemical reaction – water. Similarly, other students from the category PRT2 had missed one or two substances in their answer.

7.3.2 STUDENTS' COMMENTS ON LEARNING WITH TEXTUAL REPRESENTATION

After reading the text, students were asked about their opinions on the advantages of obtaining information from this particular type of representation. The majority of the students considered the textual representation (both the paragraph and the equation) explains the photosynthesis process and introduced all the factors affecting its rate. Students' comments, such as, "It's a good background like it tells you what is, what's actually occurring and then I think this kind of expands on it, it makes it more clear" (student 7); "It explains the process in detail, like what it's used for and what happens" (student 8) when referring to the text showed that they are confident with the learning from this representation.

7.3.3 EXTRACTING STUDENTS' INTERPRETATIONS OF THE DIAGRAM

While initially learning with the text, students were given two line charts showing the effects of light intensity, temperature, and carbon dioxide on the photosynthetic rate (Figure 7.4). After reviewing the diagrams for a period of time, students were required to debrief the information they have learnt from those two line charts. The responses to this interview question indicated that all students were able to identify the biological expertise suggested by the diagram, that is, the photosynthetic rate could be affected by the intensity of the substances such as sunlight and carbon dioxide.

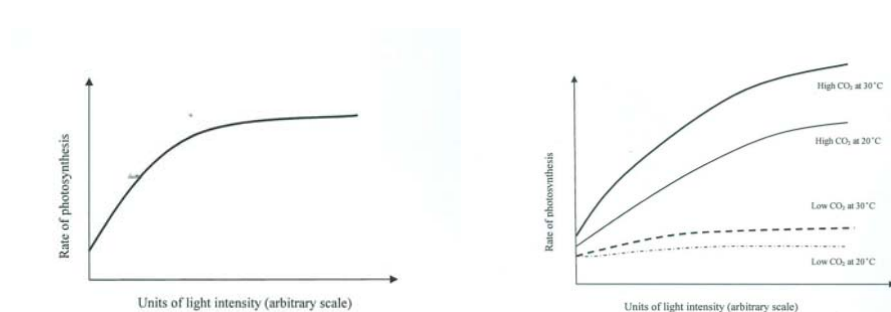


Figure 7.4 Diagrams used in complementary function

Table 7.6 Summary of Students' Responses to Diagrammatic Representation about 'Factors Affecting Photosynthetic Rate'

Code	Explanation	Number (Percentage)
PRD	The rate of photosynthesis increases along with the light intensity and peaks in this area. The light intensity increases, so does the photosynthetic rate. And when there's a high rate of CO ₂ , a high amount of CO ₂ , there's a higher rate of photosynthesis.	11 (100%)

From the interview, it was apparent that the line charts helped students understand the significance of the influencing factors that had an impact on the photosynthetic rate. The following excerpt supports the inference that students identified the relationship between different substances:

Interviewer: Have a look at these charts please. Can you find out those factors affecting photosynthetic rate through reading these charts?

Student 7: Well yeah, the light intensity, temperature and CO₂.

Interviewer: Just describe what's happening in the charts please?

Student 7: Well, so as the light intensity increases, the rate of photosynthesis increases but up to a certain point and then it's, it kind of even out there. And then with CO₂ and temperature, when the temperature's higher, the rate of photosynthesis is higher. And when there's a high rate of CO₂, a high amount of CO₂, there's a higher rate of photosynthesis.

Another evidence to show the student demonstrated his understanding from learning with the charts:

Interviewer: Now have a look at this chart please. So tell me what are the factors that influence the photosynthetic rate?

Student 6: The units of light intensity and temperature, carbon dioxide, yeah.

Interviewer: So explain in detail please how could the light intensity influence the photosynthesis?

Student 6: Well the higher the intensity of the light causes a higher rate of photosynthesis.

Interviewer: What about carbon dioxide?

Student 6: Well the higher level the carbon dioxide is and the higher the temperature, the higher rate of photosynthesis occurs, but when it's low carbon dioxide at a lower temperate it just stays at a fairly steady level.

Overall, the students' answers concerning the interview question 'Can you understand those factors affecting photosynthetic rate through line charts?' (see Appendix 3) demonstrated they all have generated a sound understanding from interacting with the other mode of representation - the diagram. Students have described their understanding of the biological concept through interpreting the line charts. Moreover, their explanations have contained all the relevant substances that may have a role to play in influencing the photosynthesis. The students identified the variables including light intensity, CO₂, and rate of photosynthesis shown either on the x-axis, or y-axis in the charts. In addition to that, they also figured out the complex relationships that have been represented pictorially in the diagrammatic representation (as in Appendix 3).

7.3.4 STUDENTS' REFLECTIONS ON LEARNING WITH DIAGRAMS

Representations that contain the same information still differ in their advantages for learning in certain situations due to the extent to which they support computational offloading, re-representation or graphical constraining (Ainsworth, 2006). The researcher therefore also investigated every interviewee's opinions on the characteristics of diagrammatic representations in conveying meanings. In general, students consider the diagrams used in depicting the photosynthesis to be more visually friendly as they displayed the data changes in detail. On the one hand, students were able to find those dependent variables on the charts, such as light intensity and carbon dioxide. Student 3 commented that: "It (the chart) shows exactly what the effecting factors are, which is light, temperature and carbon dioxide". Student 4 commented that: "It (the chart) shows the effects that certain factor changes will make on photosynthesis. Like its effects of concentration of carbon dioxide, temperature, and light intensity". On the other hand, the researcher noted that some other students also noticed the effects of factor changes. Student 2 remarked that "It (the chart) proves that CO₂ and light has an effect, and show how much effects it has". "It shows that they (the substances) are dependent of one another (student 8)". A much detailed explanation can be found in student 7's remark "This (the chart) tells you specific amounts, like it's saying, as the factors increase so does the rate. It shows you specifically of how much it increases by". The diagrammatic representation in this case appeared to demonstrate the domain knowledge in a different way as it allows the students to understand the domain much efficiently.

7.3.5 THE COMPARISONS BETWEEN THE TWO REPRESENTATIONS

Though representations differ in the advantages of demonstrating the domain, learners may benefit from each of the individual representations (Ainsworth, 2006). In investigating if students' learning has been supported by the combining representations, the researcher intended to ascertain how the students could choose to work with the representations for information that suits their learning. There was a range of student responses to the interview questions such as "Is there any connection between the text and diagram? Is it likely for students to understand the

content only by relying on one representation?” The most common responses related to the connections of the information contained between the two different modes of representations; all of the participant students, indicated that they could realize there are some sorts of connections between the text and line charts being presented to them. Student 10 remarked “well this one [the text] sort of talks about more what photosynthesis is, where this one [the diagram] talks about what affects it more. But yeah, there are connections because they talk about the same sort of elements and stuff [light intensity, CO₂ and etc.]” Student 7 explained that “Well yeah, there is, it’s kind of showing you the same process that’s happening, but in different forms, and yeah, it’s just a different way of saying the similar kind of thing.” The overall response to this question was very positive. This result indicated that students appeared capable of identifying the representational attributes of diagram and text that seem to be critical for the individual’s understanding of the representations and the domain.

The researcher asked the students to take this opportunity to reflect upon their own learning experience that might be generated from the interaction of both representations. The follow-up questions may motivate students to reflect about their representational learning experience further. Students were then encouraged to imagine whether or not they could achieve a complete understanding solely by depending on the diagrammatic representation with no information from the text. Once again, the most common response to this question was negative. Though the response from students 6 and 10 was “yes” at the beginning, but they later emphasized they need to have some “background knowledge” or “extra information” to assist their interpretation. Therefore, the researcher would rather consider they could not have their learning accomplished only by relying on one single representation.

The other nine students found it would be “quite hard” (student 4) or “would not be as easy to understand” (student 1), as they believed the diagram and the text were demonstrating different types of information. Student 1 further explained that “with the text, you can tell the waste products, and you can understand the process. But the diagram is in specific detail, like factors affect photosynthesis.” A similar reason can also be found from student 4 who commented that “The text tells you that what substances are needed for the photosynthesis. But you can see how much differences

it makes by reading the charts.” It should be noted that learners have benefited and realized the unique advantages of the two representations.

7.3.6 LEARNING OUTCOMES OF THE COMBINING REPRESENTATIONS

In investigating the learning outcomes of interacting with both representations, the researcher presented the diagram and text to the students and asked if they could develop a better understanding about the biological concept photosynthesis after learning with the text and diagrams together (see Appendix 3). The responses to this interview question indicated that all students gave the affirmative answer, which suggests their learning could benefit from switching between the two representations.

Table 7.7 Summary of Students’ Learning Outcome When Two Representations Are Employed

Code	Explanation	Number (Percentage)
Affirmative Answers	Yes, I think so. Because the text tells what photosynthesis is and the diagram is good for telling you how the factors affected with the diagrams. So learning with diagram and text together can give you a good understanding of the concept.	11 (100%)
Negative Answers		0 (0%)

As shown in table 7.7, students’ responses became clearly evident that they all believed the learning of the content knowledge can be much facilitated by the usage of more than one representation. Because students believed the functions of the two different representations vary and therefore, they are suitable for attaining different types of information. This difference appeared to have been unanimously recognized by all every interview participant. Similar responses can also be found:

Interviewer: Can you have a complete understanding about learning this topic?

Student 11: Yeah, I think yes. Because the text tells what they are, and with diagrams it is easy to understand the differences it would make on the photosynthesis.

Student 5 also felt his learning could benefit from making use of both the diagram and the text. His comments are as follow:

Student 5: They are both about photosynthesis, but there are sort of different things on the same topic. Such as this one [text] is the requirement for understanding photosynthesis, while this one [diagram] shows what affects the rate of photosynthesis. So I think the text is a very generalised way of looking at it, whilst the diagram is a more practical way of looking at it. It gives me background knowledge as to what is photosynthesis, what has been used in the process. The diagram really shows a practical example of the rate of photosynthesis. If you want to look at it from pure facts, then the text is good, but if you want to actually, like, bring it into the real world, like use your understanding of what you've learned into a real life situation, then the diagram is really useful.

The implication from the above responses is that students found the representations to have their own unique advantages in explaining certain information. Only by learning with one single representation either diagram or text, the student can hardly understand the biological knowledge that needs the learner's interpretation go across different levels. Students' affirmative answers to this interview question also confirmed that an improved learning outcome could be achieved if both representations were considered.

Multiple representations complement each other because they differ in the processes that each supports or in the information each contains (Ainsworth, 2006). Due to the complementary functions, it is expected that learners can benefit from the representational characteristics of the individual representations. The complementary function happens when the interpretation of one representation has been supported by another representation, and consequently students could be able to benefit from switching between the representations.

7.3.7 COMPLEMENTARY INFORMATION FUNCTION

Having determined the factors related to the use of representations in providing complementary functions in learners' learning, multiple representations are considered to provide complementary information when there are some different information contained by each representation. Meanwhile, one representation has been supported by the other in the learning process. In this study, the diagrammatic and the textual representations have different advantages of demonstrating information; students were considered to benefit from the learning with both of the two representations in the end. The multiple representations learning environment should allow the learners to take advantages of each individual representation for understanding the expertise. The interview process has engaged interpretative

research methods in an attempt to explore the complementary process that may facilitate students' learning of the biological content.

To keep track of students' learning of the representations, the corpus of interview data collected in this study suggested students realized that different types of information has been contained by the diagram and the text. In addition to that, the two types of representations also differ in their representational features through which the domain knowledge been demonstrated.

As the findings shown above (see Table 7.7), students considered that the textual representation to be 'more comprehensible' because it explains 'the background knowledge' telling 'the whole photosynthetic process and what's actually occurring'. By reading the written text, students were able to understand the information contained within this particular representation. The content knowledge students obtained from learning the text included:

- The substances required for the photosynthesis. Students mentioned 'carbon dioxide, water, sunlight, and chlorophyll.'
- The products of photosynthesis. 'Glucoses, oxygen, and water'.
- All the substances written in chemical symbols. Such as ' CO_2 , $\text{C}_6\text{H}_{12}\text{O}_6$, and O_2 '.

While it should be noted that students obtained some other information from learning with the diagrammatic representation (see Table 7.6). Meanwhile, the unique representational features also have been recognized by the learners (see Table 7.6). In general, students considered the charts used in depicting the photosynthesis to have more advantages in the displaying the data changes in a quantitative way, as they allow students to see the changes much apparently. The domain understanding that students obtained from learning the diagrams include:

- The substances required for the photosynthesis. Students mentioned 'carbon dioxide, water, sunlight, and chlorophyll.'
- The relationships between variables. 'Rate of Photosynthesis and Light Intensity'.
- The changes of the data. 'Line curves on the charts'.

Further, students were found to have benefited from learning with the two representations together (see 7.7). The combination of diagram and text had enabled students to become more familiar with the concept, as students gave indication that a much thorough understanding had been achieved from learning with the combining representations at last.

According to the examination of students' learning process, it was reasonable to propose that the function of complementary information has been applied to the diagram and the text. In learning the biological concept – photosynthesis, different information has been contained by the representations. Students could hardly obtain all the information so as to make sense of the representational attributes in which various chemical substances affecting the photosynthetic rate. However, the diagram and the text started to complement each other when they both were presented in the learning. Students then were able to solicit sufficient information to understand the domain. Hence, students' learning efficacy has been improved by engaging both representations. And this learning outcome may not occur if a single representation would be enough for the learning. Therefore, it could be argued that diagrammatic representation and the text representation complement each other.

7.4 KIDNEY FUNCTION

The interview protocol – kidney function was used to examine students' learning of the biological content through diagram and text (see Appendix 3). Once again, the researcher solicited students' understanding from the diagrammatic representation and the textual representation respectively. Different learning outcomes were then examined so as to determine the representational relations (if there any) had been identified by the diagram and text. Particularly, students were given a schematic diagram showing the kidney function in which different processes are involved, such as filtration, reabsorption, secretion, and excretion (see the chart below).

Later, students were presented with a short paragraph of written text that summarizes all the above mentioned functions with detailed explanations. An equation was listed to help students understand the complete kidney function (see Appendix 3). Students'

interpretation of this biological concept could therefore be analyzed relating to their representational learning experiences.

7.4.1 SOLICITING INTERPRETATION OF THE DIAGRAM

The diagrammatic representation was introduced to students before the textual representation. This schematic diagram is designed to have lots of content knowledge synthesized with many different sized arrows and annotation. Figure 7.5 was the schematic diagram used in the interview:

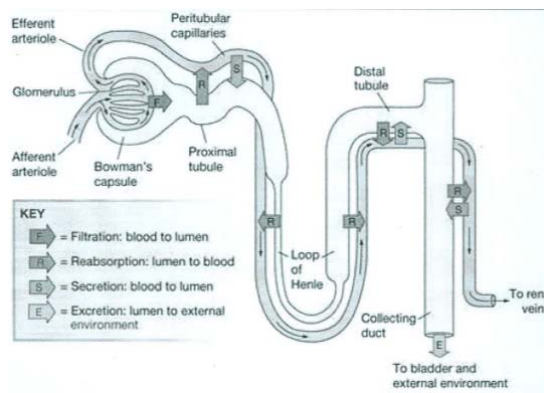


Figure 7.5 Diagram used in the constructing function

Students' learning can be classified into three hierarchies, students of PKD1 category seemed to have a complete and correct understanding of the biological concept – kidney filtration; students of PKD2 could identify not as complete amount of content information as PKD1 students did; and the explanations of PKD3 indicated that students of this category has almost no knowledge about the biological concept.

Table 7.8 Coding for Students' Responses of the Meaning by Learning with the Diagram in Interview Item – Kidney Function (n=11)

Code	Explanation	Number (Percentage)
PKD1	The blood goes into Glomerulus, small particles are excreted out into the lumen; some of the particles inside are excreted, they are actually useful in the blood. Some of the useful particles are reabsorbed by the part called peritubular capillaries. And in the end, urine is excreted that sends down to the collecting duct, to the bladder, and it excreted out of the body.	5 (45.45%)
PKD2	The blood goes into the glomerulus and then stuff is filtered through into the proximal tubule. Nutrients waste and – just like the basic stuffs. The contents of the blood is reabsorbed and then filtered through. The stuff that's not reabsorbed just goes out. The useful stuff, like the nutrients will go back to the blood.	4 (36.37%)
PKD3	Students' explanation of this category seemed to be containing no relevant expertise. Their understandings of the biological concept were quite limited.	2 (18.18%)

7.4.1.1 Students Classified As Having a Complete Understanding (PKD1)

It could be argued that students of the category PKD1 have learnt sufficient amount of domain knowledge about kidney function. Their responses suggested that: on one hand, they could identify the different phases of the function – Filtration, Reabsorption, Secretion, and Excretion. On the other, they all gave examples about the changing of substances in each phase.

Interviewer: Please explain the concept shown by the diagram.

Student 2: It is about the blood is filtered through the kidney and erected by urine.

Interviewer: Can you explain from the very beginning.

Student 2: It is the kidney.

Interviewer: Why do you think this is the kidney?

Student 2: Because it is from the glomerulus, and arteriole that connect to the kidney.
I know from the lumen to the bladder.

Interviewer: How does the kidney function in the diagram?

Student 2: It filters blood to the lumen, and then it gets reabsorbed by the blood.
Some of them get secreted back in, and reabsorption all way through the secretion.

Interviewer: What are these parts?

Student 2: This is the capillary, and that has some glucose left over and good stuff back goes back into the blood. So there is no wastes, all the wastes just goes, and there are just good stuffs.

Interviewer: Can you tell me what are the good stuffs and which are bad stuffs?

Student 2: Glucose

Interviewer: Glucose is good?

Student 2: Yeah. Oxygen, minerals, vitamins. And the bad stuffs are maybe urea.

According to the student 2's response, he has identified a number of kidney functions such as 'reabsorption', 'secretion' in his conceptual understanding. Through reading the diagram, student 2 has referred the apparatuses such as 'glomerulus', 'arteriole', 'capillary' contained in nephron, the basic working units of kidney that the functions take place. Later, he also discussed the substances that have been processed by the kidney such as 'glucose', 'oxygen', 'minerals', 'vitamins', and 'urea'. All these detailed responses could serve as a powerful indication to show that the learner has developed a thorough learning outcome by interacting with the schematic diagram.

7.4.1.2 Students Classified As Not Having a Complete Understanding (PKD2)

Students' understanding classified under the category PKD2 contains less complete interpretations. Although most of the PKD2 students were able to find out the four salient functions of kidneys, they could not tell the details such as what substance (blood) goes into the urinary system, and what has been filtered at each stage. Some of them could not call the terminologies annotated by the diagram, like the lumen and etc. A typical response of this kind can easily be found in student 11's answer:

Interviewer: Just explain in detail the information you can have learnt from this diagram?

Student 11: There's filtration of blood from, blood to lumen, and then reabsorption of lumen back to blood. Then in secretion the blood goes into lumen, and then in excretion of it goes from lumen to external environment. Yeah, that's all I can tell.

Interviewer: So what is lumen?

Student 11: The lumen? I don't know.

Interviewer: Alright, so can you tell me the substances have been changed from the very beginning of the diagram? What come into the system?

Student 11: Blood.

Interviewer: And what are the substances been reabsorbed?

Student 11: Sorry, I don't know.

Student 11 identified the functions such as 'filtration', 'secretion' and 'reabsorption' but could not give any further information about the substances changed during the process, except 'the blood' goes into the glomerulus. In addition to that, this student could not refer to the terminologies in his explanation. Instead, he skipped some details and explained by jumping from 'blood to lumen' to 'goes from lumen to external environment'. Therefore, a response of this kind suggested that the student does not fully understand was classified as less complete.

7.4.1.3 Students Classified as Having a Limited Understanding (PKD3)

Two students have been categorized under PKD3, because they have learnt quite limited information from the diagram. Firstly, they were not able to tell the four functions of kidneys; secondly, they had no idea about the substance changes during the process; and lastly, they could not explain the expertise by referring to the annotations. The language used in their explanations was only non-scientific everyday language. Here is an exemplar response from PKD3:

Interviewer: Explain the concept shown by the diagram please.

Student 3: It describes the kidney filtration. I can tell things coming into the kidney, and goes out at the end of the system in the end.

Interviewer: Can you describe what has been changed from the beginning until the end of this diagram?

Student 11: Water? Urine? And wastes.

Student 6 also had limited understanding about the concept:

Interviewer: Please explain in detail what concept shown by the diagram?

Student 6: Okay, basically it's showing the pathway from the... I think, the kidneys or ...

Interviewer: Do you think this is a kidney or part of a kidney?

Student 6: Well it says kidney function so I'm guessing it is the kidney.

Interviewer: Do kidneys look like this?

Student 6: I don't think so. It's such a long thing. I am not quite sure.

Interviewer: Okay, can you explain from the very beginning?

Student 6: Okay, so the urine will go in through the arterial and ... The urine will travel through the kidneys and the capillaries and ...

Interviewer: Any other substances go with the urine?

Student 6: Is it blood, or ... lumen

Interviewer: What is lumen?

Student 6: I'm not sure and, yeah, and then the urine will sort of mix with the blood and the lumen and travel out through all the tubes and is eventually excreted into the external environment.

It is apparent from the responses above that both student 3 and student 6 had only obtained vague understandings about the kidney filtration. Due to their limited interpretation or background knowledge, the language they used in describing the expertise was non-scientific, such as “things coming into the kidney” (student 3), “such a long thing” (student 6). The descriptions of their learning were not precise and thorough enough and they deliberately skipped some information that they are not sure of. Moreover, non-scientific conceptions were also found from student 6's interpretation: “it says kidney function so I'm guessing it is the kidney”. This alternative conception occurred because the student was not quite aware of nephron is the basic structural and functional unit of the kidney. Therefore, students of PKD3 could hardly develop any further understanding about the diagram.

7.4.2 EXTRACTING INFORMATION FROM THE TEXT

The second stage of the interview procedure requires the researcher to investigate what specific domain knowledge that interviewees can have by learning with the textual representation (see the text in figure 7.6).

TEXT

The urinary excretion depends on the three fundamental functions of filtration, reabsorption, and secretion.

Filtration – the blood is filtered by nephrons, the functional units of the kidney.

Reabsorption – the process by which solutes and water are removed from the tubular fluid and transported into the blood. It is called reabsorption because these substances have already absorbed once.

Secretion – the transfer of materials from peritubular capillaries to renal tubular lumen.

$$\text{Filtration} - \text{Reabsorption} + \text{Secretion} = \text{Excretion}$$

Figure 7.6 Text used in the constructing function

After retrieving the information contained within the diagrammatic representation, students were presented with a short monograph relating to the same biological concept – kidney function. The researcher attempted to investigate students' conceptual learning when text is presented.

The interview data suggested that the 11 interview participants were all able to describe the domain knowledge explicitly through learning with the textual representation, even for the students who were found to have obtained limited content knowledge from the diagram (PKD3). Once again, an equation (Filtration – Reabsorption + Secretion = Excretion) was introduced to synthesize the whole process. An evidence showing students' interpretation of the textual representation can be summarized as follow: “The entire process of urine excretion can be divided into three steps: The blood is filtered by the nephron; reabsorption happens when the blood reabsorbs the solute from the water; and the materials like the unwanted secretion materials are secreted from the capillaries to the lumen.” This result therefore can be assumed that the textual representation was very helpful in delivering the content knowledge to students when the diagrammatic representation was perceived to be too complicated.

7.4.3 INDIVIDUAL PREFERENCE FOR CHOOSING REPRESENTATIONS

Since the diagram and text bear unique representational features in displaying information during students' biological learning process, learners thus may find either of the two representations to be of more advantages to attain the expertise. As discussed in the previous sections, both the diagram and the written text were found to contain detailed explanations of the kidney functions in different formats – visual or written words. After dealing with both modes of representations, the researcher sought every interview participant's opinion on judging the difficulty of learning with each of the representation and the role it plays in the biology learning.

Table 7.9 Coding for the Individual Preference of Representations (n=11)

Code	Explanation	Number (Percentage)
KFP1	Prefer text to diagram	7(63.64%)
KFP2	Prefer diagram to text	3 (27.27%)
KFP3	Invalid answer due to lack of domain knowledge	1(9.09%)

As shown in the Table 7.9, seven out of the 11 students considered the text facilitated their learning better than the diagram. Their reasons for choosing the text over the diagram to learn the concept include: “It (text) is much simpler. The chart is quite hard to understand, but the text has three simple paragraphs and they are easy to read and easy to understand. The text has the same order with the diagram, it tells you what happens in there (student 2).”; another response from student 5 indicated that the equation in the text could helped her obtain the holistic understanding: “I can see there’s a certain – the function of excretion, so it needs these three other factors, filtration, reabsorption, secretion, each to work independently These functions happen in a flow. From the equation, I can see that they all rely on each other and the text goes into a brief detail about each of these functions, but not much more is given.” For those who prefer to learn with text, they believe the textual representation provides information that can be much directly interpreted, even they don’t have adequate background knowledge. By reading the paragraphs, they learn the information without recognizing the biological entities drawn in visual format.

While some other students found that the diagram was more efficient in demonstrating the content knowledge. Only three students tended to choose the diagram as the preferable representation type. Their reasons are as follow: “It (diagram) makes more sense by showing what happens and where it happens, whereas here the text doesn’t exactly specify like where everything locates (student 8).”; student 10 also emphasized the importance of seeing the information, as he said “Because the text can’t make me really visualise what it means. But I can see what happens in the diagram... like the arrows help you to see which way stuff is going and where like the blood capillary is and where the kidney is and stuff like that.” Unlike the students who prefer to learn with the text, KFP2 students tended not only to know what the kidney functions are and what happens during the urine secretion process, but also they tended to draw a clear picture in their mind showing where exactly the relevant entities are located. Interestingly, these visual learners appeared to be those students who are of high achievements and have better domain knowledge.

One student was classified under the category KFP3, because this student could hardly interpret any relevant information from the representations. Due to the students’ limited domain knowledge, the interview process went into silence several times. The researcher would believe that student 4 not only had difficulty in attaining the biological learning, but also unable to compare the different representational features between diagram and text. His response to the biological topic was rather superficial and non-informative.

7.4.4 INFORMATION EXTENSION BETWEEN THE REPRESENTATIONS

Multiple representations support the construction of deeper understanding by extending a learner’s knowledge from a known to an unknown representation, but without fundamentally reorganizing the nature of knowledge (Ainsworth, 2006). In order to explore the collaborative effects that diagram and text may exert on the biological learning, the researcher examined students’ reflections on knowledge transference between the two representations. In the interview process, the posed the question ‘Can you extend some of your understanding between the diagram and the

text?’ and students’ responses about the kidney function will be examined in this section.

Table 7.10 Coding for the Individual Opinions on Information Transference between Representations (n=11)

Transference happened or not	Direction of transference	Explanation	Number (Percentage)
Positive	From Text to Diagram	Information in the text improved the understanding of diagram	8(72.73%)
	From Diagram to Text	Information in the diagram improved the understanding of text	2 (18.18%)
Negative/Invalid	---	No information transference occurred	1(9.09%)

Students were able to achieve their conceptual learning by integrating the information from the diagram and text. In particular, students’ understanding from one representation source may serve as a basis for the interpretation of the other unfamiliar representation. Learners’ understanding of the familiar representation might be transferred to another representational learning environment. As shown in the table 7.10, 10 students admitted that their biological learning could be extended from one representation to the other, either diagram or the text. One student’s answer was classified as negative or invalid response, because this student could not answer this interview properly and his previous responses also confirmed his lack of domain knowledge. Among the students who had identified information transference, eight students preferred to extend their individual learning benefited from learning with the textual representation. In other word, 72.73% of the students referred to the information from the text in order to interpret he diagram.

Here is an example from student 1 showing the content information been transferred from the text and then integrated into the understanding of the diagram:

Well, I bring from the text to the diagram. The blood goes into Glomerulus and arrow F – filtration, I can understand nephron filtered this stuff out into the lumen, which is this tube. Reabsorption, which is R in the chart. I can relate them in the text and diagram. I can tell what is reabsorbed, goes back into the blood. And the secretion part is the same thing, I can know where it is secreted from, what is secreted and etc. and etc. (student 1).

Another detailed response from student 5:

From text to diagram. By reading the diagram, I would not have a very good understanding at the beginning, but later I gained the knowledge from the text to fully support my understanding of it. During this process, I could see the links in the text and diagram. For example: when I read the definition of the filtration, and I could see the visual things on the diagram. So I immediately remembered what this definition means. And also for the equation, I could relate it to my understanding of the diagram. What participated, and what remained. Basically, I can correlate all the definitions with the diagrams (student 5).

Student 1 and student 5 admitted that with the content knowledge learnt from the textual representation, their learning of the diagrammatic representation could be much facilitated. They understood the concepts by reading the definitions in the written text, and these previously obtained conceptions could help learners to identify the biological knowledge depicted by the diagram. As students mentioned they were able to identify the relevant associations between the two distinct representations. Consequently, students were able to extend their understanding from one single representation to the situation where another unfamiliar representation is engaged.

Ainsworth (2006) defined that the constructing function happened in the following three occasions: *Abstraction*, when learners create mental models that serve as the basis for the construction of new concept at a higher level; *Extension*, when the knowledge has been extended from a familiar to an unfamiliar situation without fundamentally reorganizing the nature of that knowledge; *Relational understanding* is the process when two representations are associated without reorganization of knowledge. Ainsworth (2006) also indicated that the construction functions depend upon learners' knowledge and their goals of learning. Therefore, exploring of students' understanding may serve as a basis for identifying the construction functions of the multi-representational environment.

7.4.5 CONSTRUCTING FUNCTIONS BETWEEN DIAGRAM AND TEXT

7.4.5.1 Constructing by Information Extension

Multiple representations support the constructing of deeper understanding when the information has been extended from a known representation to an unknown

representation, and has not been fundamentally reorganized (Ainsworth, 2006). When diagram and text were introduced into students' biological learning, students were found to have their biological learning accomplished by extending information from text to diagram, or vice versa.

By looking back into the interview process, students may reach different learning outcomes by referring to the two distinct representations, respectively. Some may prefer to learn with the text, because 'the text explains more to you and it doesn't just say this is what happens, it describes what the process is and why it happens (student 6)'; while some others would like to learn this topic by relying on diagram, as the diagram allowed them 'to see how the urine and the blood travels, and again it shows the excretory system organs., like the veins and everything (student 9). Students chose either diagram or text as their favorite representation, from which the domain knowledge could be picked up by the learners much easier.

Information extension can be considered to have occurred in the students' learning, as students admitted that they could transfer some learning from one representation to the other (see results 7.10). The information has been extended from a known situation (either diagram or text) to an unknown or less known situation (text or diagram). For the interview participants who believed that some information could be transferred from text to interpret diagram, the textual representation thus constructed their interpretation of the diagrammatic representation. Student 1 proved a thorough understanding of the diagram was achieved with the assistant information from the text. He explained the biological domain knowledge with more confidence in the end: 'during the filtration, the arrow shows the blood goes into the lumen. Substances like urea were filtered from the blood. And the diagram tells where it is filtered from and where it filtered to. Reabsorption, I borrowed understanding from the text. I know the arrow means that stuff from the lumen filtered into the capillaries. With the text we can know that things are filtered back into capillaries and solute in the water'. Therefore, the constructing function applied to the students' conceptual learning.

7.4.5.2 Constructing by Relational Understanding

Multiple representations support the construction of relational understanding, which needs the learner to associate two representations without reorganization of knowledge (Ainsworth, 2006). Building up the connections between representations can sometimes be considered to be the goal of learning in itself (Ainsworth, 2006). The researcher found that when the combination of diagram and text were introduced in the biological learning, the goal of learning may also lie in having learners relate the contents from both representations. When learners interpreted the domain knowledge from one representation, they are also expected to construct their learning with another type of representation, i.e. the relation between representations.

Evidence indicated that learners were able to perceive the similarities in the conceptions contained by the diagram and text when both representations were engaged in the biological learning. For example, student 6 described how she found the same content information from the diagram and text: 'I am guessing both diagram and text are talking about filtration, absorption, and secretion.' She also realized different representational features played particular roles in demonstrating the domain: 'The text explains more to you what everything is and why it happens, but it doesn't tell where everything happens. While the diagram shows where each process happens in the cycle. It shows all the details.' The overall response of student 6 revealed that the relation between the two representations has been identified during the individual's representational learning. Student 6's integration of the biological knowledge from both representations could also be considered to be the process of constructing the deeper understanding of the domain.

Another learner could also understand how different formats of representations related to each other in conveying the domain knowledge. Student 5 reflected his learning outcomes from the diagram and the text: 'I would have not a very good understanding by reading the text, but later I can see its links with the diagram. Such as, the definition of the filtration, I immediately related my understanding from the text to the interpretation of the diagram. The corresponding knowledge from the diagram and text fully supported my overall understanding of this biological concept.' Apparently, the student 5 achieved the insight that would be difficult to be obtained with only a single representation. Furthermore, the insight achieved in one

representational format was transferred to another representational learning situation. Learners constructed references across multiple representations that expose the underlying structure of the domain represented.

7.5 SUMMARY AND RESPONSE TO THE RESEARCH QUESTION

This chapter has reported research findings that in regard to answer Research Question 7: What are the roles that diagrams and text have when learners relate both representations to understand biological concepts. Students' interpretative process has been described by which the researcher developed a set of interview protocols to investigate how multiple representations are integrated with each other to assist students in making sense of complicated biological domain knowledge. Each of the three interview protocols contained textual and diagrammatic representations that allowed the researcher to compare individual's conceptions gained from both sources.

It is apparent that diagram and text differ in their roles in having students process the domain knowledge. There are three key cognitive functions applied to the learners' learning when the combination of diagram and text are employed in the learning secondary biology: to constrain, complement and construct.

Diagram and text would constrain the each other in demonstrating information. This may occur if the information is too complicated to be presented by the single representation, either diagram or the text. Furthermore, individual's interpretation may be constrained by different representational properties (see section 7.2); constraining function could also be achieved when learners have different familiarities toward the representational formats.

Diagram and text may complement each other when they differ in the information that each representation contains. As a result of learning with the combination of diagram and text, learners could benefit from the advantages in each of the representations (see section 7.3).

Diagram and text may construct learners' coherent understanding when learners were not able to achieve the insight with only a single representation (see section 7.4). In particular, students' coherent understanding of the domain knowledge can be

achieved by relating the diagram and text; or by extending the conceptions between representations.

CHAPTER 8

CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

8.0 CHAPTER OUTLINE

In this chapter, a brief outline on how the research questions in the study were answered is presented. The data collected during the study provides the basis for the conclusions, recommendations and discussion on the limitations of the study.

8.1 SUMMARY OF THE STUDY AND CONCLUSIONS

This research has examined the role of diagrams in teaching and learning secondary biology, specifically teachers' organizations of their classroom instruction and students' interpretation of multiple representations. There are four objectives of this research: firstly, to understand how different types of diagrams are distributed in the textbooks; secondly, to investigate teachers' instructional use of diagrams in the everyday biology teaching; thirdly, to examine students' perceptions of teachers' instructional use of diagrams; and fourthly, to explore the cognitive roles that diagram and text play in students' understanding of biological concepts.

These four objectives correspond to the research questions of the study, which draw together the research methods, data collection, and data analysis throughout this study. The seven research questions which guided this quantitative and qualitative data analysis were:

1. What kind of diagrams are students exposed to when learning science and biology in senior high school?
2. How are diagrams distributed in textbooks?
3. What are development trends of the diagrammatic usage in the textbook?
4. How did teachers choose to use different types of diagrams when teaching secondary biology?

5. What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?
6. What are students' perceptions of teachers' instructional strategies with diagrams?
7. What are the roles that diagrams and text have when learners relate both representations to understand biological concepts?

Research Question 1- 3 established the content basis for the investigations in this study. The content analysis of the diagrams used in secondary biology textbooks and classroom teaching was described in chapter 4. The content analysis of the diagrammatic representations includes:

- The frequencies of diagrams in the textbooks.
- The distribution of the diagrams in different grades of biology textbooks.
- The trends of the diagrammatic usage across textbook types.

Table 8.1 Research Objectives and Research Questions

Research Objectives	Research Questions
Phase One	RQ1 What kind of diagrams are students exposed to when learning science and biology in senior high school?
	RQ2 How are diagrams distributed in textbooks?
	RQ3 What are the development tendencies of the diagrammatic usage in the textbooks?
Phase Two	RQ4 How did teachers choose to use different types of diagrams when teaching secondary biology?
Phase Three	RQ5 What are the dimensions that biology teachers need to be aware of when diagrams are used in the teaching?
	RQ6 What are students' perceptions of teachers' instructional strategies with diagrams?
Phase Four	RQ7 What roles do diagrams and text play when learners relate both representations to understand biological concepts?

The first three research questions focused on diagram use in secondary biology education from the perspective of textbooks. After examining and cataloguing 5340 diagrams, the researcher feels confident that the diagrammatic classification

completely characterizes diagrams in each secondary biology textbooks. It was found that diagrams were frequently employed in the textbooks, and students' workbooks. Previous studies argued that different domain knowledge and conventional rules used in the images could have an impact on students' learning (Pozzer & Roth, 2003; Roth et al., 2005). This result may suggest that different diagrammatic features were employed in the biology teaching and learning. The distribution patterns of diagrams and their trends of usage in different years' textbooks could also have an impact on secondary students' learning. The results have been cross checked by my supervisor and another scholar so as to improve the inter-rater reliability of the study. An agreement was reached about the criterion used in classifying diagrams among those examiners. The diagrams in dispute were examined and classified once again.

Research Question 4 was answered in Chapter 5 where teachers' instructional use of diagrams was reported from classroom observations of how teachers use diagrams to improve their students' understanding of abstract biological concepts. Research Question 5 was addressed by four assertion statements generated from observation of biology teachers' teaching. Different diagrams were employed in different instructional purposes, such as introducing the topic, instruction and evaluating students' learning, explaining with the analogical features. The empirical study of teachers' teaching together with the content analysis of textbooks provided holistic understanding about the diagram usage in the secondary biology teaching. The researcher viewed diagrams as pedagogical tools that require flexibility in their usage (Cheng & Gilbert, 2009). The assertions provided in chapter 5 should be seen as an example of the everyday instructional practice of teaching secondary biology with diagrams. These assertions provide a fertile basis for the development of pedagogical repertoires of diagrammatic inclusion in secondary biology education.

Research Question 5 was answered in Chapter 6 through the administration of the instrument measuring Students' Perceptions of Biology Teachers' Diagrammatic Usage. The salient aspects of the instructional use of diagram were identified from the analysis of the results. The questionnaires were administered to 215 Grade 9 and Grade 10 students from four biology teachers' classes in one senior high school. The factor analysis indicated that students showed particular attention into three major aspects of the diagrammatic instruction that includes instruction with diagrams,

assessment with diagrams and students' diagrammatic competency. Research Question 6 was answered through the administration of the instrument Measuring Students' Perceptions of Biology Teachers' Diagrammatic Usage to senior secondary students. The development of instrument was based on the procedures described by a previous validated instrument (SPOTK) evaluating students' perceptions of teachers' pedagogical knowledge (Tuan et al., 2000). The original four scales and 24 items in the instrument were developed based on the content framework established in Chapter 6.

The results obtained from data analysis indicated that the instrument on measuring students' perceptions of biology teachers' diagrammatic usage has satisfactory validity and reliability measures. The uniqueness of the instrument is that it is specifically related to students' perceptions on teachers' diagrammatic instruction within a particular teaching and learning environment that includes diagrams. This is important because research has shown that teachers' instruction influences students' perceptions of the learning environment (Fraser, 2012; Tuan et al., 2000). The effective teachers' instructional use of diagrams may always include having students engaged in the different phases of biology teaching and maintain favourable classroom learning environments.

Based on an explicit constructivist view of teaching, one of the features of teachers' pedagogical content knowledge was considered the teacher to be able to plan the teaching and learning environment (Cochran, DeRuiter, & King, 1993). Consequently, the researcher believes that the instrument measuring students' perceptions of biology teachers' diagrammatic usage can be used to investigate the relation between teachers' diagrammatic instruction and students' perceptions on their own biology learning in terms of Instructional Repertoire, Assessment Repertoire and Competence Repertoire. By examining the results from administration of the instrument, the researchers and teachers can identify those aspects of their teaching that need to be improved in order to match students' needs and expectations.

Research Question 7 was answered through administration of an interview protocol for secondary students' interpretation of diagram and text. The qualitative data obtained for this purpose were described in chapter 7. These results were explored so

as to determine how diagrammatic and textual representations integrate to provide unique benefits when students were learning complicated biological concepts. The comparison of the conceptions generated by learning with diagram and text showed that the combinations of representations can play a number of functions in supporting students' learning. The functional framework proposed by Ainsworth (Ainsworth, 2006, 2008b) initially addressed the educational value of multimedia usage in the students' learning. More recently, some studies focused on analysing the multiple representations used in everyday teaching and learning environment. This study has further illustrated the utility of different visual representations in pencil-and-paper context. It was found that the functional roles between diagram and text were complementary, constraining and constructing.

The analyses indicated that, overall, secondary students could recognize the relevant information from diagram and text, respectively, to learn the target biological concepts. Though individual preferences of learning with representation types vary, the information gained from both representations could contribute to evolving new and coherent understanding. Thus, diagram and text have different functional roles in forming students' conceptual understanding.

The three different roles that diagram and text could play in supporting learning have been acknowledged. Diagram and text can complement each other when each representation contains different information in the learning process. Because single representation would be insufficient to carry all the information about the domain, learners can benefit from the advantages of each of the individual representations by combining diagram and text; students were able to develop a better understanding by using one representation (either diagram or text) to constrain their interpretation of the second representation (either text or diagram). The constraining function was achieved by employing a familiar representation (diagram or text) to support the interpretation of the less familiar one (text or diagram). The constraining function was achieved by learners' taking advantage of the inherent properties of representation; diagram and text also support the construction of deeper understanding such as extending the interpretation from a known to an unknown representation, making association between both of the representations.

8.2 LIMITATIONS

Several limitations have been identified in this study. These include: the number of textbooks and workbooks analysed, the interpretive analysis of content taught by teachers, the selected number of pedagogical repertoires and propositions tested in the instrument, the lack of follow-up interviews, researcher's bias subjectivity, and the pencil-and-paper tests.

8.2.1 THE NUMBER OF TEXTBOOKS AND WORKBOOKS ANALYSED

Only nine Western Australian textbooks and workbooks were analysed in this study to determine whether they are consistent with the diagram distribution catalogued in the study. As there are more biology textbooks for secondary school in other states and many more commercial workbooks, the findings in the chapter 4 therefore cannot be generalised for all nation-wide secondary biology textbooks and workbooks. The results of content analysis would refer to the most frequently used nine textbooks and workbooks in Western Australia.

8.2.2 THE INTERPRETIVE ANALYSIS OF THE CONTENT TAUGHT BY TEACHERS

Although a total of 92 biology lessons were observed, five teachers from one high school were willing to participate in the research. Even if the five biology teachers were experienced and were interested in using visuals in their own classes, the research did not examine how diagrams were engaged in experimental activities and practical work in the laboratory environments due to limited opportunity and time constraints. In addition to that, the participating teachers' teaching tended to be more didactic; this may be decided by the instructional facilities and equipment available, school culture and tradition, and students' habit of learning. To some extent, it may also be worthy of investigating some teachers whose teaching tends to be less didactic but more student-centred. Thus, the small sample of participant teachers might have affected the investigation of teachers' instructional use of how diagrams are incorporated in everyday biology teaching.

8.2.3 THE SELECTED NUMBER OF PEDAGOGICAL REPERTOIRES AND PROPOSITIONS TESTED IN THE INSTRUMENT

Among the various kinds of teachers' knowledge, the literature provided the substantial and essential framework for a knowledge base of teaching (Shulman, 1987; Wilson, Shulman, & Richert, 1987). This framework included content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational context, and knowledge of educational ends, purposes and values. The instrument used in the study was not specifically designed to contain all those aspects indicated by previous teachers' pedagogical content knowledge research. More pedagogical repertoires concerning teachers' use of diagrams could have been included and investigated by the instrument.

8.2.4 THE LACK OF PRE-TEST AND FOLLOW-UP INTERVIEWS

The researcher did not interview any students before or after the administration of the questionnaire. The identification of students' opinions has not been sought before developing the items tested in the instrument related to teachers' teaching practice. Though the items in the instrument were cross-checked by several biology teachers, it might be the case that students' comments are also worth inspecting. The textual representations have to be presented to the interview participants so as to compare their understanding of the text with the diagram. This is determined by the research design and theoretical framework. Hence, further validation of the findings of the results determined by the instrument could also been achieved by having follow-up interviews. There are several possible reasons for necessity of conducting follow-up interviews: on the one hand, students might not be able to "perceive and interpret test statements in the way that test designs intent" (Hodson, 1993), though a great effort was spent in redesigning the instrument; on the other hand, careless or impatient attitudes could cause students to guess answers, which could have affected the validity and reliability of the test.

8.2.5 RESEARCHER'S BIAS AND SUBJECTIVITY

There may be the possibility of oversimplification or exaggeration of the situation in the interview data analysis leading to conclusions that may not accurately represent reality. The researcher's intentions when analysing the cognitive roles of diagram and text about each individual's biological concept learning may not fully describe and explain the different functions in their learning. This outcome is likely because the differences between functions of multiple external representations are subtle even though they are reflected in students' learning (Ainsworth, 2006). The viability of representational functions between diagrams and text is therefore judged by the researchers' interpretation according to the most salient functional feature demonstrated by the learners' responses. For example, an explanation suggesting constraining function may be interpreted as a complementary function as explained by the reader. Appendix 5 shows some of the transcribed interview data. Given that the researcher was the interviewer and coded the transcribed data in conjunction with his supervisors, there may be bias in the data interpretations. Nevertheless, students' responses were strictly coded and judged according to a theoretical framework (Ainsworth, 1999, 2006); meanwhile, strategies such as peer debriefing and member checking with his supervisors were used to address this limitation.

8.2.6 THE LACK OF PENCIL-AND-PAPER TESTS

There are also problems for not having pencil-and-pen tests engaged in the interview protocol. The interview data were mainly to determine the cognitive relationship between students' interpretation of diagrams together with text when they are used in learning different biology topics. The interview protocol required students to comment on the cognitive roles that each representation plays through the explanation of the domain knowledge. Students may not have understood or may have misinterpreted the biological knowledge and chose not to seek further clarification. Also, students' ambiguous conceptions may have affected the validity and reliability of the findings. The students may never have thought about the concept or phenomena before, but to invent something to answer the researcher's questions. The value of having a written test may give the researcher additional advantage to examine students' real understanding about the domain. It can therefore be assumed that a more explicit examination of students' conceptions may help

improve the diagnosis of educational functions in a multiple representations environment.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Several aspects that can be addressed by future research into the use of diagrams in biology education. Following the progress of the studies in this thesis, a number of research questions can be identified in the area of textbook use of diagrams, teachers' use of diagrams, and students' interpretations of diagrams.

8.3.1 TEXTBOOKS' USE OF DIAGRAMS

Content analysis of textbooks in this research identified a range of different diagram types used in a number of Western Australian secondary biology textbooks. Further research of a more systemic manner is required to investigate what diagram distribution patterns that textbook authors find appropriate to demonstrate biological concepts. Research in this field should also employ qualitative and quantitative analysis of survey instruments to determine how different diagram distribution patterns are employed in the biological concepts. For example, similar or closely-related biological topics may share the same diagram distribution pattern and could help decide when a diagram needs to be supported with textual explanation.

8.3.2 TEACHERS' USE OF DIAGRAMS

The study has summarized some characteristics of teachers' instructional use of diagrams (see chapter 5). Further research is needed to examine whether these teaching practices are broadly implemented in other secondary biology teaching circumstances and to ascertain how this teaching can improve students' conceptual learning. Hence, there is a need to investigate the manner in which other biology teachers implement different types of diagrams in their normal classroom routines. In a similar manner, classroom observation techniques and post-observation interviews could be used to analyse more biology teachers' instruction. These findings may therefore be broadly used in promoting pre-service teachers' diagrammatic usage.

Further studies could also include engaging instruments to determine students' perceptions of teachers' various diagram usage in the classroom teaching. During the development process of the instrument, only three distinct aspects of teachers' instructional usage were identified as being viable - Instructional Repertoire, Assessment Repertoire, and Competence Repertoire. Future research could examine other aspects of teachers' knowledge from students' perceptions such as contextual knowledge, curriculum knowledge, and knowledge of students. Of interest also is whether the instrument and students hold the same constructs of the various kinds of teachers' instructional use of diagrams and if it does not, to decide how to identify students' own perceptions of the various aspects of teachers' diagrammatic teaching. By solving these emerging issues, it is likely that a better understanding of students' perceptions of biology teachers' teaching performance will be achieved.

Therefore, to establish the new instrument's usefulness, future research is needed to provide more specific analysis concerning the relationship between this instrument and students' responses to the items by interviews. Other research is needed to examine whether biology teachers with acknowledged good performance on the three scales identified by the study, including Instruction, Assessment, and Competence, would be scored higher on the three scales of instrument compared to teachers with weak performance.

8.3.3 STUDENTS' USE OF DIAGRAMS

Chapter 8 has proposed several possible representational relationships related to students' interpretation of biological concepts shown by diagram and text. In addition, the researcher acknowledges the need for empirical research that examines the learner's diagrammatic competence in which 'the diagrammatic knowledge' (Novick, 2006, p. 3) could be influenced by learners' acquiring conceptual knowledge. Because diagrams differ in their features of representing information, there is a necessity for learning the requisite conventions to understand the diagrams (Novick, 2006). Therefore, it is important to understand what constitutes diagrammatic literacy in science education that plays a critical role for assisting learners to attain the domain-specific knowledge.

From this perspective, the call by Catley et al. (2005) to encourage biology educators to incorporate students' diagrammatic reasoning into the curriculum so as to aid changes in students' conceptions, provides a valuable insight. Appropriate methods for such a study may use interviews and surveys to probe students' conceptual changes. These studies would address questions related to how students' diagrammatic knowledge and knowing linked to their biological conceptual learning.

8.4 CONTRIBUTIONS TO THEORY BUILDING

Over the past three years, the researcher had opportunities to present the findings of these studies to national conferences both of the science education research community and the education community. The appended list (see Appendix 4) documents the conference presentations and proceedings.

8.4.1 THE INSTRUCTIONAL USAGE OF DIAGRAMS IN BIOLOGICAL TEACHING AND LEARNING

As mentioned above, the research findings from chapter 5 encouraged the researcher to consider the pedagogical use of visual representations in science teaching and learning. Diagrams are ubiquitous in science education and depict important tools for learning and reasoning about structures, processes, and relationships. The analysis of the diagrammatic distributions and the trends across lower and upper secondary general textbooks may provide some important insights on the understanding of how scientific content knowledge is presented to secondary students, by means of this particular mode of representation. Meanwhile, consideration of this diagrammatic distribution as a view of the representational nature of diagrams and appropriate pedagogy can help inform the instructional routines in which teachers organize their teaching of conceptual knowledge. Rather than viewing diagrammatic teaching as a fixed means of demonstrating content information, it could be viewed as a process of more scientifically engaging a series of instructional practices. Teacher's scientific instructional use of diagrams may have a role to play in not only solving students' problem and difficulties of viewing various biological phenomena directly, but also eliminating the difficulty of interpreting and relating multiple levels of

representations toward acquiring scientific understandings (Gilbert & Treagust, 2009). In addition, three major scales were identified in the instrument regarding biology teachers' need to consider how and when diagrams are integrated in the teaching: Instruction with Diagrams, Assessment with Diagrams, and Students' Diagrammatic Competence.

8.4.2 THE FUNCTIONAL RELATIONSHIPS BETWEEN DIAGRAM AND TEXT

The conceptual framework for considering students' learning with multiple representations was discussed in the chapter 2. This multiple representation learning framework integrates research on cognitive science of representation and constructivist theories of education. It also proposes that the effectiveness of multiple representations can best be understood by considering three fundamental aspects of learning: the design parameters that are unique to learning with multiple representations, the functions that multiple representations serve in supporting learning, and the cognitive tasks that must be undertaken by a learner interacting with representations (Ainsworth, 2006). This study extended the usage of the multiple representations framework to the analysis of learners' learning of biological concepts when static and non-simulated representations are engaged in comparison with computer simulations. It is suggested that diagram and text differ in their roles as students process the domain knowledge. The three key cognitive functions of learners' learning with a combination of diagram and text in secondary biology are to constrain, complement and construct.

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APPENDICES

APPENDIX 1

TEXTBOOKS ANALYSED IN THE STUDY

- Anderton, J., Hopfmueller, V., King, E., Leahy, J., Linstead, G., Lindberg, B., Wood, D. (2004). *Fundamentals of science: Book 1* (2nd ed.). Melbourne: Longman.
- Anderton, J., Hopfmueller, V., King, E., Leahy, J., Linstead, G., Lindberg, B., Wood, D. (2004). *Fundamentals of science: Book 2* (2nd ed.). Melbourne: Longman.
- Anderton, J., Hopfmueller, V., King, E., Leahy, J., Linstead, G., Lindberg, B., Wood, D. (2004). *Fundamentals of science: Book 3* (2nd ed.). Melbourne: Longman.
- Anderton, J., Hopfmueller, V., King, E., Leahy, J., Linstead, G., Lindberg, B., Wood, D. (2004). *Fundamentals of science: Book 4* (2nd ed.). Melbourne: Longman.
- Greenwood, T., Shepherd, L., Bainbridge-Smith, L., & Allan, R. (2008). *Year 11 biology: Student workbook*. QLD, Australia: BIOZONE International Ltd.
- Greenwood, T., Shepherd, L., Bainbridge-Smith, L., & Allan, R. (2006). *Year 12 biology: Student workbook*. QLD, Australia: BIOZONE International Ltd.
- Huxley, L., & Walter, M. (2000). *Biology: An Australian perspective* (2nd ed.). Australia: Oxford University Press.
- Newton, T., & Joyce, A. (2009). *Human perspectives: Book 1*. Australia: Cengage.
- Joyce, A., & Newton, T. (2009). *Human perspective: Book 2*. Australia: Cengage.

APPENDIX 2

SUMMARY OF ALL BIOLOGICAL CONTENTS IN TEXTBOOKS EXAMINED

Fundamentals of science Book 1

Life Processes

Cells
Growth and Nutrition
Movement and Response
Respiration and Excretion
Reproduction

Animals

Classification of Animals
Single-Celled Animals
Simple Animals – Sponges and Jellyfish
Worms of All Types
Animals with Spiny Skins or Shells
Animals with Jointed Legs
Animals with Backbones
Humans and Other Animals

Plants

Classification of Plants
Simple Plants – Algae, Mosses and Liverworts
Complex Green Plants – Ferns and Conifers
Flowering Plants
Fungi and Lichens
Humans and Plants

Fundamentals of science Book 2

The Human Body

The Skeletal and Muscle Systems
The Digestive System
Respiration and Temperature Control
Blood Circulation and Excretion
The Reproductive System
The Nervous and Immune Systems
Healthy Living

Ecology

Ecosystems and Energy
The Non-Living Environment
The Living Environment
Adaptations
Upsetting the Balance of Nature
Conservation

Fundamentals of science Book 3

Genetics

Cells and Cell Division
Asexual and Sexual Reproduction
Inheritance
Human Genetics
Heredity, Environment and Natural Selection
The Application of Genetics and Biotechnology

Field Biology

Studying the Environment
Soil
Identifying Organisms
Studying Populations
Protecting the Environment

Fundamentals of science Book 4

Genetics

Cells, Chromosomes and Genes
Reproduction
Inheritance
Human Genetics
Heredity, Environment and Mutations
Populations and Natural Selection
Applications of Genetics and Biotechnology

Biology: An Australian Perspective

Introduction to Biology

The Nature of Biology

The Diversity of Life

Classifying Organisms

Overview of Living Organisms

Phylogenetic Relationships

The Effect of Organisms on Humans

Ecology

Organisms and Their Environment

Populations

Ecosystem Dynamics

Communities and Their Habitats

Human Impact on the Environment

Animal Behaviour

Animal Behaviour

Cell Biology

Chemicals of Life

Cell Structure

Cell Functions

The Functioning Organism

Plant Physiology

Plant Reproduction, Growth and Development

Animal Physiology

The Human Body

Human Reproduction, Growth and Development

Genetics

The Inheritance of Characteristics

Gene Action

Evolution

Theories of Evolution

The Mechanism of Evolution

Biotechnology

Biotechnology

Human Perspectives Book 1

Human Biological Science
Investigating
Cells Exchange Materials
Cells at Work – Cell Metabolism
New Cells
Transport to and from Cells
Input and Output: the Lungs and Alimentary Canal
Output: the Kidneys
Protection against Invaders
Production of Gametes
Reproductive Cycles and Fertilisation
Pregnancy
Birth and Development
Cell Differentiation
Healthy Pregnancy
Making Choices about Contraception
DNA – the Code for Life
Principles of Inheritance
Characteristics of Offspring
Sources of Variation in Humans
Mutations
Making Informed Choices
Human Biology and Everyday Life

Human Perspectives Book 2

Investigating Scientifically
Cellular Activity
Cell Protein Production
Chemical Messengers
The Central Nervous System
The Peripheral Nervous System
Nerve Impulses and Autonomic Responses
Homeostasis of Body Temperature and Body Fluids
Homeostasis of Blood Sugar, Gas Concentrations and Blood Pressure
Disruptions to Homeostasis
Specific Resistance to Infection
The Skeleton
Working Muscles
Inheritance
Evolutionary Mechanisms
Evidence for Evolution
Fossil Evidence for Evolution
Primate Evolution
Evolution of the Human Species
Medical Technologies

Biotechnology

Student Resource and Activity Manual 1

Skills in Biology
Cell Structure
Cellular Processes
Nutrition
Gas Exchange
Transport and Excretion
Reproduction and Development
The Principles of Classification
Environment and Adaptation
Communities
Population Dynamics
Practical Ecology
The Origin and Evolution of Life
The Evolution of Australia's Biota
Changes in Ecosystems

Student Resource and Activity Manual 2

The Chemistry of Life
Homeostasis
Control and Coordination
Defence and the Immune System
Pathogens and Disease
Non-Infectious Disease
The Genetic Code
Gene Technology
Mutations
Inheritance
Population Genetics
The Evidence for Evolution
Evolution
Human Evolution

APPENDIX 3



Grade: _____ Gender: _____ Date: _____

Students' perceptions on science teachers' use of biology diagrams

Directions for students:

- This questionnaire contains statements about the teaching of biology in your class.
- The statements refer to biological topics such as respiration, photosynthesis, etc.
- You will be asked what you yourself think about these statements. There is no 'right' or 'wrong' answer. Your opinion is what is wanted.
- Think about how much you agree with the statement as it applies in your biology class.
- For each statement, draw a circle around

- 1 if you **STRONGLY DISAGREE** with the statement;
- 2 if you **DISAGREE** with the statement;
- 3 if you are **NOT SURE**;
- 4 if you **AGREE** with the statement;
- 5 if you **STRONGLY AGREE** with the statement.

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another.

Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

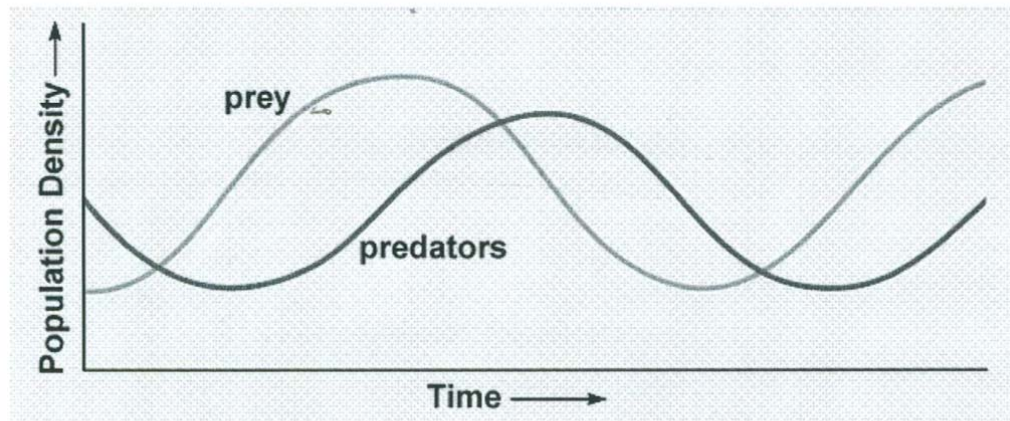
IR	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
1. My teacher's methods of teaching with diagrams keep me interested in science.	1	2	3	4	5
2. My teacher provides opportunities for me to draw diagrams expressing my point of view.	1	2	3	4	5
3. My teacher uses different kinds of diagrams to help me understand biology concepts.	1	2	3	4	5
4. My teacher's teaching methods make me think hard about a particular diagram.	1	2	3	4	5
5. My teacher uses a variety of diagrams when we study different biology topics.	1	2	3	4	5
6. My teacher's use of a variety of diagrams enables me to have a better understanding of a certain biological concept.	1	2	3	4	5
RR	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
1. My teacher uses diagrams that are familiar to me to explain biology concepts.	1	2	3	4	5
2. My teacher uses a wide variety of visuals (pictures, graphs and charts) to explain biology concepts.	1	2	3	4	5
3. My teacher uses models to help me understand biology diagrams.	1	2	3	4	5
4. My teacher shows how the written text helps explain a biology diagram.	1	2	3	4	5
5. My teacher shows how the diagram explains the written text.	1	2	3	4	5
6. My teacher uses analogies with which I am familiar to help me understand a particular diagram.	1	2	3	4	5

AR	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
13. My teacher's tests evaluate my understanding of diagrams of a biology topic.	1	2	3	4	5
14. My teacher's questions evaluate my understanding of diagrams while the teaching is in progress.	1	2	3	4	5
15. My teacher uses different approaches (questions, models, etc) to find out whether I understand the meaning of a diagram.	1	2	3	4	5
16. My teacher assesses the extent to which I understand a diagram.	1	2	3	4	5
17. My teacher's tests allow him/her to check my understanding of diagrams.	1	2	3	4	5
18. My teacher adjusts the teaching strategy with diagrams in response to the feedback of our learning of concepts.	1	2	3	4	5
CR	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
19. Diagrams can be confusing when there is too much abstract information.	1	2	3	4	5
20. The process of going from less abstract diagrams to more abstract diagrams suits my learning better.	1	2	3	4	5
21. Diagrams are made up of a certain amount of detail, which requires special skills to interpret.	1	2	3	4	5
22. Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn.	1	2	3	4	5
23. The biology concepts shown in a diagram can be static or kinetic.	1	2	3	4	5
24. When I can explain a biology concept with different types of diagrams, I feel more confident about my learning.	1	2	3	4	5

APPENDIX 4 INTERVIEW PROTOCOL

Population dynamics – predator and prey relations

Diagram



Text

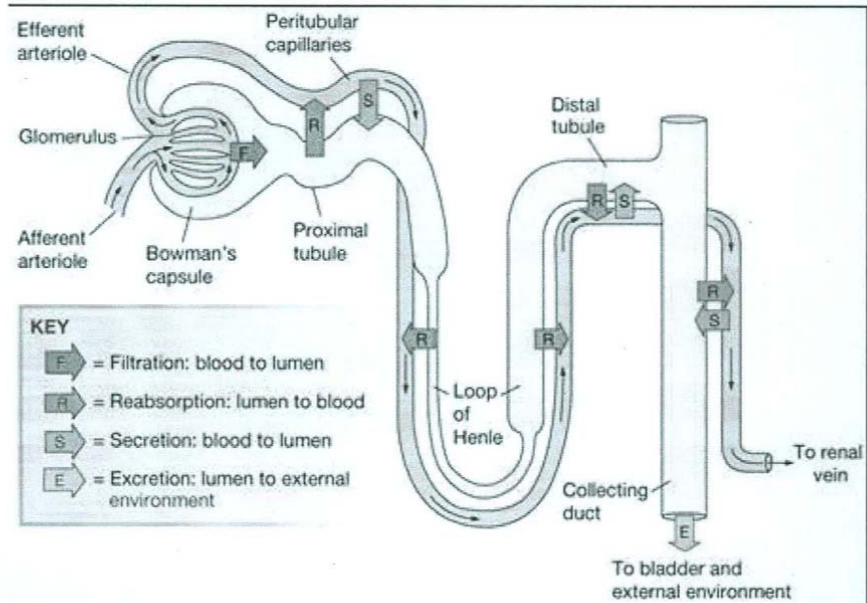
What actually happens in nature is that a cycle develops where at some time the prey may be abundant and the predators few. When the number of predators is scarce the number of prey should rise. As the number of predators rises, the number of prey decline. Because of the population density of prey, the predator population grows and reduces at regular intervals according to the fluctuation of population of prey. Therefore, the predator oscillations always lag behind the prey oscillations.

Predator and prey

1. Please describe the biological concept suggested by the diagram?
2. What specific information can you learn from this diagram?
3. Please describe in detail what the paragraph is about?
4. Which of the two – diagram or the text helps you understand the biological concept better?
5. For you, do you develop a better understanding by reading this diagram and text together?
6. Can you give me two examples of this predator and prey relation?
7. Due to the human population, most predator and prey relations are no longer natural. Can you give an example of this?

Kidney function – urinary excretion

Diagram



TEXT

The urinary excretion depends on the three fundamental functions of filtration, reabsorption, and secretion.

Filtration – the blood is filtered by nephrons, the functional units of the kidney.

Reabsorption – the process by which solutes and water are removed from the tubular fluid and transported into the blood. It is called reabsorption because these substances have already absorbed once.

Secretion – the transfer of materials from peritubular capillaries to renal tubular lumen.

Filtration – Reabsorption + Secretion = Excretion

urinary excretion

1. Explain in detail the concept shown by the diagram?
2. What is meant by luman?
3. What are the visual advantages for you to learn from the diagram?
4. Describe in detail what you have learnt from the text?
5. Do you prefer to read the diagram or the text?
6. Can you extend some of your understanding between the diagram and the text? Like from to the paragraph to diagram, or vice versa. What are they?
7. What do the arrows represent? What is their meaning?

Section 3

Requirements for photosynthesis

Text:

Photosynthesis is of fundamental importance to living things because it converts solar energy into chemical energy stored in molecules, releases oxygen gas as a waste product, and absorbs carbon dioxide. Chlorophylls is used to absorb the light energy.

Photosynthesis is summarized in the chemical equation below:

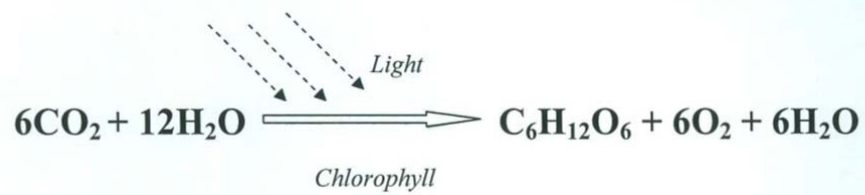


Diagram: Factors Affecting Photosynthetic Rate

Fig 1: Effect of light intensity on photosynthetic

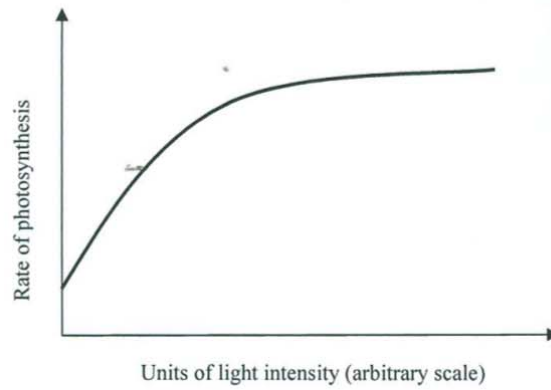
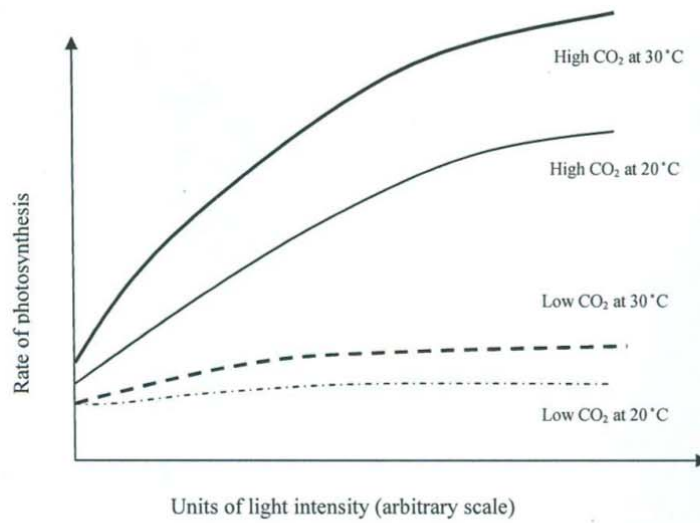


Fig 2: Effect of light intensity, temperature, and CO₂ on photosynthetic rate



Photosynthesis

1. Explain the process of photosynthesis shown by the text?
2. What do you think are the factors that affect the photosynthetic rate?
3. What do you think is the advantage to learn with the text?
4. Can you understand those 'factors affecting photosynthetic rate' through those line charts? Can you explain this to me?
5. What is the advantage to learn with the diagrams?
6. Is there any connection between the text and diagram? What is it?
7. Without the information shown by the text, can you understand the content in the diagram?
8. After learning with the text and diagrams together, are you able to develop a complete understanding about the concept photosynthesis and the factors affect photosynthetic rate? Please explain your understanding to me.

APPENDIX 5

CONTRIBUTIONS FROM THIS RESEARCH

Liu, Y. & Treagust, D. F. (2011). *An interpretive examination of high school biology teachers' use of diagrams*. Paper presented at the 42nd annual ASERA conference. Adelaide: Australian Science Education Research Association.

Liu, Y., Treagust, D. F., & Won, M. (2011). *The development of an instrument for assessing students' perceptions of science teachers' instructional use of biology diagrams*. Paper presented at the annual conference of the Australian Association of Research in Education. Tasmania: Australian Association of Research in Education.

Liu, Y. & Treagust, D. F. (2012). *The functional roles for considering learning biological concepts with diagrams and text*. Paper presented at the 27th annual forum of Western Australia Institute for Educational Research. Fremantle, Perth: Western Australia Institute for Educational Research.

APPENDIX 6

TRANSCRIBED INTERVIEW DATA

Interview 1

PREDATOR AND PREY

I: Please describe the biological concept suggested by this diagram?

S: I think it would mean that, once the prey's number is getting high ... gets too high, the predator's number.. or population grows high as well. And once the predator's number grow high, they eat prey, they hunt down the prey, the prey's number goes down. Therefore predators don't have enough food, and the number goes down as well.

I: So how do you know they don't have enough food?

S: Well, the prey's number was going down, so predators won't have enough food.

I: The food is the main reason?

S: Yeah.

I: What is the specific information you can have from this diagram?

S: The population numbers of prey and predators.

I: Now have a look at the paragraph. Please tell me in detail, what does this paragraph tell you?

S: What it means is ... when there is less predators, the prey number will rise. The prey number rises, the predator number rises as well, because there is more food. But when the predators rise, the prey number drops. And the prey number drop, the predator number drops. And the cycle starts again.

I: Which of the two, the diagram or the text helps you understand the biological concept better?

S: The text. I think the text is more in-depth, because I can understand more in detail. But the diagram is easier to take in and understand. Like the lines.

I: Can you develop a better understanding about this topic by reading the diagram and text together?

S: Yeah.

I: Just give me some examples please. What kind of complete understanding you can have?

S: Diagram is sort of visualized; it allows me to initially understand of the concept. With what you initially understand, you read the text, you get more in-depth. You can build on the diagram like what the image say in your mind.

I: Good. Can you give me some examples about this predator and prey relation in real life?

S: Two examples?

I: Yeah, in real life.

S: Like cat and mice.

I: explain it a little please.

S: A lot of mice in say.. some one's house. There is a cat, and there are lots of mice. So the cat eats the mice, because it can eat the mice and they reproduce, so the cat number is growing. They eat too much mice, the number of mice drops. Then some cats starve to death, because there is a gap, the number of mice rises again. And the cat eats the mice and reproduces and the cycle goes on again.

I: But there is only one cat in the family.

S: Maybe there are two cats.

I: I think you have developed a good understanding about this concept. Due to the human's intervention, the relation of predator and prey is no longer natural. Can you give an example about the human intervention?

S: Maybe fish, like two kinds of fish in the ocean. Just like said that. One kind of fish feeds on the other fish. Because of the human fishing industry, the number of fish caught can cause the death of other fish that feeds on it, therefore, the number has dramatically dropped. So the predator won't have enough food. The number of the fish, which is the prey does not rise again, because human continuously fish on both of them. So maybe predators won't get enough food, maybe they get extinct or whatever.

Interview 2

KIDNEY FILTRATION

I: Please explain in detail, what is the concept shown by the diagram?

S: It just when waste from the blood is excreted in the kidney and it is excreted in the urine.

I: Can you explain part by part of the diagram, for example, what is lumen?

S: The lumen is just the tube thing. The tube that carries the excretion. What happened is, when the blood goes into Glomerulus, because of the high pressure. Small particles are excreted out into the lumen; some of the particles inside are excreted, they are actually useful in the blood. Human bodies can't afford to dump all out, some of the useful particles are reabsorbed by the part called peritubular capillaries.

I: Like what, what useful stuffs are?

S: proteins and whatever. And then urine is excreted. And in the end, it sends down to the collecting duct, to the bladder, and it excreted out of the body.

I: what are the visual advantages for you to learn from those diagrams?

S: it is easy to take in. arrows and labels are easy to take in. If I was given a text that explains this, I am not gonna to really understand. Because it is really complicated.

I: now please read this paragraph. Please tell me what you have learnt from this paragraph?

S: it breaks down the entire process - the urine excretion, into three easy simple steps. But you don't get the visual advantages of the diagram.

I: no, no I am just asking about the text.

S: Yeah, so there are three steps. The blood is filtered by the nephron which is functional unit. Some solutes in the water, some reabsorbed in the blood, and the materials like the unwanted secretion materials is secreted from the capillaries to the lumen. It also gives you a equation like down bottom one.

I: Are the diagram and the text talking about the same thing?

S: Yes, I think so. The text doesn't give step by step almost, with the diagram you can see the whole thing going on at once.

I: Did the text mention nephron?

S: Yeah.

I: Can you find nephron in the diagram?

S: No you can't.

I: So what is the first part of the diagram?

S: I think the entire thing is nephron. I remember I learnt this in human biology.

I: Can you extend some of the understanding between the diagram and text? Like from the paragraph to the diagram.

S: Can I link ...?

I: Yes, can you borrow some information from text to understand the diagram? Or diagram to the text?

S: Well, I bring the text to the diagram. The blood goes into Glomerulus and arrow F – filtration, I can understand nephron filtered this stuff out into the lumen, which is this tube. Reabsorption, which is R. I can relate it here, which in the text, it explains in detail. I can tell what is reabsorbed, back into the blood. And the secretion part is the same thing, I can know where it is secreted from, what is secreted and etc and etc.

I: So the diagram is much easier for you, or the text?

S: The diagram.

I: So you can borrow something form the diagram, or from the text?

S: I think I can do both, but it is easier to borrow from the text.

I: The last question for this item. What is the meanings of the arrows?

S: Arrows? Arrows is the direction in this case, it indicates the directions of particles of substances?

I: What substances?

S: Like the filtration. During the filtration, the arrow shows the from blood into the lumen. What I mean is, substances like urea filtered from the blood to the lumen. And you can tell where it filtered from and where it filtered to. Reabsorption, I borrowed understanding from the text. I know the arrow means that stuff from the lumen filtered into the capillaries. With the text that we can know that things are filtered back into capillaries and solute in the water.

I: can you tell me the changes of substances from the very beginning to the end? From the left side.

S: The changes from left. A lot of stuff filtered into the lumen.

I: Like what?

S: Like protein, urea, not necessarily blood. And then, I don't remember one of them cannot be filtered in. It either can be protein or the glucoses, because one of them is too big to be filtered. Vitamins, minerals. Once it goes down, reabsorption happens, some of the useful stuff just like vitamins, minerals have reabsorbed into the blood. Some of the non-useful stuff like urea, is excreted into the lumen. And it does again and again until in the end, all those useful stuffs have reabsorbed back into the blood. And all the non-useful staff is excreted into the lumen. In the end, the blood contains all the useful staff, and all the urea are secreted down the renal vein.

Interview 3

PHOTOSYNTHESIS

I: Can you explain the process of photosynthesis shown by the text?

S: It is in plants. It doesn't say in here, but I know it is in plants. Plants use chlorophyll to absorb light energy and then using carbon dioxide and light, they turned the light energy into chemical energy, they store in the glucoses and they produce oxygen, water as waste products.

I: what are the factors that can be affecting the photosynthesis rate?

S: the light, the chlorophyll in the plant, water, and any carbon dioxide present in the atmosphere or environment.

I: what will be the main factor?

S: should be the light. The light is the main source of energy.

I: What do you think is the advantage to learn from the text?

S: Here is an equation; from the equation you can get a basic understanding. And again, the text goes into detail. After you see from the diagram, you can understand more from the text.

I: Did you read the equation first and back into the text?

S: Yes, basically the diagram is more eye-catching. So you want to look at it first.

I: I will show you some graphs, please have a look. Please tell me what are those factors affecting photosynthesis rate?

S: the amount of carbon dioxide, temperature, and light intensity.

I: What is the advantage for you to learn from those charts?

S: It is visual, you can see the highlighted differences. How much difference in temperature, how much of a change of temperature of 10 degrees will make, and how much of a change of concentration of carbon dioxide will make on photosynthesis?

I: Is there any connection between text and diagram?

S: Yeah, of course. From the text, you can tell that one side plus light equals the other side. You can see what are the factors and the exhaust of gas. And in the charts, you can see how much differences it makes.

I: without the information shown by the text, can you understand the content in the diagram?

S: Yeah, but it wouldn't be as easy to understand. With the text, you can tell the waste products, and you can understand the process. But the diagram is in specific detail, like factors affect photosynthesis.

I: Last question, after learning with the diagram and text together, are you able to develop a complete understanding about this concept?

S: Basically, yeah. I can go into too the details. I can understand what happened, what are the factors affecting photosynthesis?

I: Just mention those factors once again please.

S: Light intensity, temperature, and carbon dioxide concentration.

I: Good job. Thanks.