CHAPTER 1

INTRODUCTION

Introduction

The more a person utilises higher order thinking skills (HOTS), the higher the ability of a person to function effectively in society (Cohen, 1980). Mechanistic reasoning which represents one of the higher order thinking skills, is the thought process which investigates how a cause brings about an effect. It is fundamental in making a judgment about cause and effect (Howick, Glasziou & Aroson, 2010; Koslowski, 1996; Schauble, 1996; Russ, Scherr, Hammer, & Mikeska, 2008). What can be considered mechanistic and how can such reasoning reflect cause and effect? A mechanism (Thagard, 1998, the term mechanism refers to mechanistic) is a system of parts that operates or interacts like those of a machine, transmitting forces, motion, and energy to one another. Machamer, Darden and Craver (2000) stated that mechanisms are entities and activities organized such that they do something, carry out some task or process, perform some function or produce some end product. These types of entities include ions, macromolecules and cellular structures while types of activities refer to what is carried out by the entities such as the lock and key mechanism for enzymes and substrates. Darden and Craver (2002) discovered how scientists used mechanistic reasoning in their search for the mechanism of protein synthesis. They stated that in building continuity of mechanistic reasoning, one must find an activity for each entity and an entity for each activity. Ultimately, chaining both entities and activities will give rise to the cause and effect of one phenomenon.

In science, progress has been made to discover new mechanisms, each with interacting parts affecting each other's motion and other properties (Thagard, 1998). For example, in understanding the complex causes that lead to cancer, scientists have discovered that environmental factors such as smoking, diet and exposure to chemicals may be related to cancer. However, when exploring deeper into the mechanism of cancer growth, it was revealed that genes in the cell had a part to play. The changes in cell growth produced by a series of genetic mutations caused by environmental factors can lead to cancer. Figure 1.1 below sums up the current understanding of the mechanism underlying cancer.

Environment		Cell		Result
Behaviours	→	Mutation in growth gene	→	Cancer tumours
Hereditary		Mutation in tumours suppressor gene		
Virus				

Figure 1.1. Mechanisms of cancer growth

Cohen and Yarden (2009) stated that the living world is an organised hierarchical structure in which the entities at one level are compounded into new entities at another level such as molecules into cells, cells into tissues, tissues into organs and organs into functional systems. For a full understanding of living phenomena, every level should be studied.

"*Today biology is concerned with the algorithms of the living world.*"

(Jacob, 1993, p.300)

Jacob's (1993) assertion indicates that at present the preferred direction for biological research focuses on the search for underlying algorithms of the living world which includes the understanding of processes and interrelations among them. The ability to explain natural phenomena is a hallmark of scientific understanding (Abrams, Southerland, & Cummins, 2001). Therefore, the versatility of the living world and its spectacular array of forms, functions and processes has triggered and inspired researchers (Barak, Sheva, & Gorodetsky, 1999).

However, Broham (2008) stated that Biology sometimes is taught as if students should be passive absorbers of a large body of facts about the world, rewarding the faithful reproduction of these facts for assessment. To be a successful Biology student means more than memorising the facts; it requires an understanding of science as a process (Alters & Nelson, 2002) and ability to give and evaluate competing reasoning (Gross, 2006).

One important aspect that has emerged from science educational research is that high achieving students are supposedly more capable of coping with higher order thinking tasks (Ahmet & Özden, 2011; Cook, Carter, & Wiebe, 2008; Coutinho, Wiemer-Hastings, Skowronski & Britt, 2005; Simons & Klein, 2007). Nevertheless, research conducted by Yu, She and Lee (2010) has indicated that low achieving students' higher order thinking skills (HOTS) such as mechanistic reasoning might not be reflected in their academic achievement. The statistical results show that low academic achievers performed better than the high academic achievers in a non-traditional test form. As such, the authors believe that the infusion of higher order thinking skills (HOTS) among low achievers is highly possible.

In Malaysia, Anwar Aly and Merza Abbas (2000) reported that the evaluation of students' science achievement is mainly focused on the product component (i.e. concepts, theories, and formulae) and does not give equal emphasis to the process component of scientific skills. Therefore, Anwar Aly and Merza Abbas (2000) concluded that high achievers in science are students who can explain the related concepts and theories and solve routine problems by using related formulae. In relation to this, Lay (2009) found that there was a significant difference in the overall mean of logical thinking abilities according to students' science achievement at lower secondary level. Nevertheless, this could be because the science achievement measured was based upon the product component.

In the context of this study, this could imply the possibility that current practices in the teaching-learning process only minimally or totally does not help low achieving students to generate mechanistic reasoning. Furthermore, school as well as national assessment practices may need to be realigned.

Therefore, one question that arises here is that if the sciences such as Biology are taught by the memorisation of facts in Malaysian classrooms (Fatima, 2007), would it be possible to help low achieving students attain higher order thinking skills (HOTS) such as mechanistic reasoning? Furthermore, is it true that low achieving students are unable to generate higher order thinking skills such as mechanistic reasoning?

The Malaysian National Education System

The Malaysian National Education System at the school level classified as government educational institutions consists of corporate education, primary education and secondary education (Ministry of Education, n.d). The pre-school education programme is for pupils aged between four and six. Primary education in Malaysia begins at the age of seven and continues for six years from to Year 1 to Year 6. Secondary education spans for five years from Form 1 till Form 5. Forms 1 to 3 are referred to as Lower Secondary, while Forms 4 and 5 are known as Upper Secondary. Most students who have completed primary education are admitted to Form 1. At the end of Form 3, students will take the Lower Secondary Evaluation or which is known as *Penilaian Sekolah Rendah (PMR)*. Based on the PMR results and the students' choice, they will be streamed into either the Science stream or Arts stream starting in Form 4. However, the Penilaian Menengah Rendah (PMR) examination for Form Three students will be changed to a totally school-based assessment system beginning 2016 (Zuhrin Azam Ahmad, 2010). Students in the Arts stream will be tailored to take subjects such as Accounts, Economics and General Science while, students in the Science stream will take pure science subjects such as Biology, Chemistry and Physics. Table 1.1 shows the overview of the Malaysian National Education System.

Table 1.1

Malaysian National Education System

School	**Level/ Grade**	**Age**
Pre-school	Kindergarten	4-6
Primary School	Year 1	7
	Year 2	8
	Year 3	9
	Year 4	10
	Year 5	11
	Year 6	12
Secondary School (Lower)	Form 1	13
	Form 2	14
	Form 3	15
Secondary School (Upper)	Form 4	16
	Form 5	17

In Malaysia, National Secondary Schools use Malay as the main medium of instruction. However, English is a compulsory subject in all schools. Since 2003, Science and Mathematics have been taught in English under the educational policy of Teaching and Learning of Science and Mathematics in English. The acronym in Malay is PPSMI. However, in 2010 the government decided to revert back to using Malay by prioritising the new strategy to uphold Bahasa Malaysia and strengthen English (The Malay acronym is MBMMBI.) To provide a soft landing in implementing the teaching and learning of Science and Mathematics in Bahasa Malaysia, both subjects are being taught bilingually from 2010 at primary and secondary schools. As for secondary schools, the learning of

Science and Mathematics will be carried out bilingually for Form Four in the year 2012, 2013 and 2014, and Form Five in 2013, 2014 and 2015. As such the national examination for Form Five will be carried out bilingually until 2015 (Ministry of Education, 2010). Therefore, in the present study, the medium of instruction for Science and Mathematics was still in English as the study was carried out in the year 2011.

The Theory of Cell

The most important discovery in Biology is the Theory of Cell, which proposed that all forms of life are composed of cell. Cells are the simplest unit of life that exhibit the functions, characteristics and how these cells are organised and operated (Bingham, 2000). Today, the word ‘cell’ signifies a more complex unit that contains a nucleus and a variety of subcellular organelles and is surrounded by a membrane (Becker, Kleinsmith, Hardin and Bertoni, 2009). To conceptualise the Theory of Cell, students of biology need to understand the discovery of cells and their function, which is summarised below.

In the early 17^{th} century, the construction of the microscope had enabled Robert Hooke to examine sections of cork (Becker et. al., 2009; Baker, 1988). He clearly illustrated boxlike compartments with empty cell walls which he called ‘cells’. Within a few years, Nehemiah Grew and Marcello Malpighi illustrated the comprehensive plant cells. This was followed by Malpighi, Anton van Leeuwenhoek, and Jan Swammerdam who became the first scientists to recognize cells in animals. The culmination in the Theory of Cell was in 1839 when botanist Matthias Schleiden and zoologist Theodor Schwann proposed that all organisms are composed of cells (Harris, 2000).

Later, Barthelemy Dumortier and Robert Remak recognized that cells arose from pre-existing cells and Virchow popularised the phrase all cells come from cells. Since then, research in cell reproduction has revealed the wondrous complexity of cells. For example, most cells contain a single nucleus that reproduces during mitosis and cell division. By the 1880s, scientists had concluded that all multicellular organisms, regardless of their complexity, emerged from a single cell. Cells are central for growth and reproduction. Since a cell is the basic unit for growth and reproduction, the cell needs to replicate and accurately pass on information at each cell division. This is achieved by a series of events called the cell cycle. However, nothing more was revealed until the discovery of the structure of DNA in 1953 (Bingham, 2000; Becker et. al, 2009; Harris, 2000).

Merging life's chemistry into cell reproduction was first articulated in the 1920s. Muller's explanation had postulated the need to look into the chemistry going on within cells. The next major discovery about biological chemistry was the enzymes. The discovery of zymase (an enzyme in yeast) by the Buchner brothers, Eduard and Hans in 1897 became the cornerstone of biochemistry. For the molecular action and chemical synthesis in cells, several enzymes have to work together to carry out a sequence of activities. This is the central principle underlying cellular organisation. To achieve this organization, the cell first has to maintain the general conditions necessary for life's chemistry (Albert et. al., 2002).

Understanding the history of the discovery of cells is important in conceptualising the Theory of Cell. This is depicted in the four topics designed in the Malaysian Form Four Biology syllabus which are related to the Theory of Cell. The four topics are (a) cell structure and cell organisation; (b) movement of substances across plasma membrane; (c) chemical composition of cells and; (d) cell division. These four topics are taught in sequence; however, it does not indicate the increase of complexity. The brief history has revealed that in order to understand the basic of the Theory of Cell, these four topics should indicate the links and the increasing complexity between them so that the students can conceptualise the whole concept of the theory of cell.

Background of the Study

Brewer, Chinn and Samaranpungavan (1998) as well as Hammer (1995) in their study have stated that, mechanistic reasoning is causal. As such, there is a need to inquire as to why students find explaining the ‘cause (how or why the main characteristics in mechanistic reasoning) of the biological processes difficult? Zohar and Tamir (1991) in assessing students’ difficulties in reasoning stated that many students tend to employ intuitive rather than giving appropriate reasoning when they are confronted with problems. This was supported by the study conducted by Abrams et al. (2001) where he claimed that most of the students failed to recognize the need to include a cause in their explanation.

Another study by Chi, Slotta, and Leeuw (1994) indicated that the difficulties in learning Biology stem from the students being unable to link different categories of the same concept (mismatch). For example, students perceived the concepts of ‘cell’, ‘cell specialisation’ and ‘cell organisation’ as different independent categories, which, in the nature of biology, all these concepts are interrelated. Hence, students find it hard to understand and are unable to explain various biological processes related to cells. Research into explicating relationships between the Biological processes continues to show that students have difficulties particularly when two or more concepts are engaged. For instance, Songer and Mintzes (1994) refer to the problematic understanding of the relationship between events of cellular respiration and various biological phenomena such as breathing, circulation, wine making and ecology. Flores (2003) revealed students’ problems in understanding the different levels of organisation of multi-cellular organisms. Cohen and Yarden (2009) also indicated that students have difficulty in relating biological phenomena with their cellular explanations.

Abram et al. (2001) claimed that for an understanding of the systemic nature of biology and the complex interrelations within and between the systems, the conception of biological concepts through processes (why and how the process takes place) is essential. Unfortunately, students' are more familiar with what Barak et al. (1999) calls the "matter concept" (it is known as entities in mechanistic reasoning). The following quote reflects the students' responses to photosynthesis that take place in plant cells with reference to the 'matter concept':

> *The light energy, the water and the CO_2 are all components that participate in the photosynthesis process. The products of this process are organic compounds and ATP*. (Students were able to state the underlined "matter concepts" but failed to explain how photosynthesis takes place) (pg. 1284)

The above quote reflects the frequent use of the 'matter concept' in their explanation by the students. There is no account of the flow of how or why (mechanistic reasoning) photosynthesis is carried out in plant cells. What it should be is that the students' answers should have more reference to the process (combination of entities and activities in mechanistic reasoning). For example,

> *The chlorophyll in plant cell absorbs CO_2, water and light energy. The first phase of photosynthesis is the light phase which through photolysis of water and the oxygen is released…the ATPs produced during photophosrilation…the second phase is called the dark phase in which the CO_2 is going through several enzymatic reactions and the glucose is produced…* (Explaining the process should involve not only entities but activities of the entities)

Verhoeff, Waarlo and Boersma (2008) showed that to acquire coherent conceptual understanding of cell biology, more effort is needed in thinking competence at the metacognitive level. Mechanistic reasoning, as stated earlier, is one of the powerful modes of thinking that should be advocated in learning science to facilitate students' explanations as to how or why one event (the cause) brings about the other (the effects).

Enhancing students thinking skills is one of the main objectives stated in the Biology curriculum in Malaysia (Ministry of Education, 2005). One of the thinking skills that is emphasised in the curriculum is reasoning which is the bridge to master creative and critical thinking skills (Ministry of Education, 2005). However, Abdullah Mohd Noor (2009) in his study showed that the change from memory-based learning to thinking-based learning was ranked as the highest constraint a teacher faced to integrate higher order thinking skills (HOTS) among students. This situation will in turn possibly cause the integration of mechanistic reasoning to be neglected and not to be emphasised.

Another aspect that the present study is concerned about is low achievers and their mechanistic reasoning. In a study by Wu and Tsai (2010) in Taiwan, it was found that differences of 'richness' of cognitive structures and information processing strategies in low achievers in a constructivist oriented science instruction learning group was significantly different from the 'richness' of cognitive structures in a traditional teaching group. According to the Education, Audiovisual and Culture Executive Agency (2011), few countries in Europe have special programmes for tackling low achievers and support is provided as part of the general framework of teaching and learning. In Malaysia, Lay (2009) stated that low logical thinking abilities might be due to an exam oriented education system as less emphasis is given to the teaching and use of thinking skills. Lay's study showed that low achievers have an overall lesser mean in logical thinking (conservational reasoning, proportional reasoning, probabilistic reasoning and combinatorial reasoning) compared to high achievers.

In the effort to develop students' logical thinking abilities, some changes in terms of the evaluation system and science teaching and learning strategies need to be seen intentionally (Education, Audiovisual and Culture Executive Agency, 2011). The following section will put forward the statement of problem for the study in relation to mechanistic reasoning which is the focus of the study.

The Statement of Problem

Consider the following example given by Riemeier and Gropengieβer (2008) in the study of cell division, when students were asked what happened to onion roots when placed in a jar filled with water:

Researcher : What has happened to the onion roots?
Student : Roots come out of the onion.
Researcher : Why does this happen?
Student : Because onion gets matured.

(p.929)

This is a typical situation in any biology classroom. Though most of the time students have learnt about certain topics in biology (in the case above - cell division), they are unable to make connections between the concepts they have learned (growth and cell division in the above case). The concepts used to describe certain biological processes have often remained fragmentary. This is because of inadequate learning of concepts taught through isolated chapters and leads to students being unable to integrate between the concepts (Verhoeff et al., 2008). When dealing with the biological world, mechanistic based explanations (which refers to mechanistic reasoning), that is explaining how things work, what are the entities and activities of the entities involved, how entities and activities bring about effect, how the property of the entities affect the activity of the entity – are necessary. Students who fail to recognise the mechanisms (mechanistic reasoning) in the process consequently have little awareness of the relationship across biological processes (Lewis & Kattmann, 2004). This explains why many students fail to acquire a coherent conceptual understanding of the cell as a basic unit of organism (Dreyfus & Jungwrith, 1988, 1989; Flores, 2003).

As for the example given by Riemeier and Gropengieβer (2008), if students were able to recognise the mechanisms for the phenomena, where mitosis (one type of cell division that takes place in cells) plays an important role in growth in producing new cells necessary to growth, they will be able to make connections between the concepts. The mechanisms involved in giving reasons for the above situation are as shown in Figure 1.2.

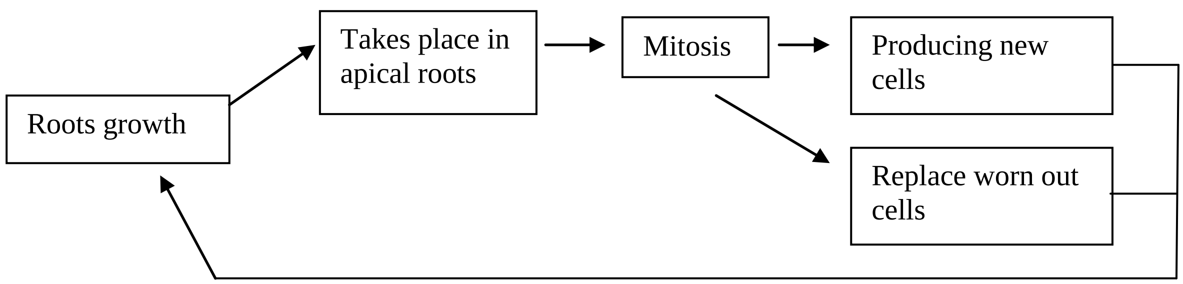

Figure 1.2. Mechanistic reasoning involved in the growth of root

Although, many researchers have pointed out the importance of mechanistic reasoning in helping students to have coherent understanding of biological concepts (Abrams et al., 2001; Janssen & de Hullu, 2008; Jordan, Gray, Demeter, Liu and Hmelo-silver, 2008; Ploger, 1991; Taylor & Jones, 2009), there are still many issues that arise with regards to integrating mechanistic reasoning. Firstly, Southerland, Abrams and Cummins (2001) found that students employed the use of teleological reasoning more frequently than mechanistic reasoning in explanations. Thus, when asked to explain how a change (mechanistic reasoning) occurred in biology, students have a tendency to respond as to why the change occurred (teleological reasoning) and not how, proving that most of the students are weak in giving mechanistic reasoning in their explanations. For example, when students were asked to explain how photosynthesis occurred (mechanistic reasoning), they explained that photosynthesis was important in producing starch using light energy (teleological reasoning). Ganeshadeva (2011) stated that students in Malaysia are assisted in acquiring thinking skills (such as mechanistic reasoning) to discover facts through their own effort and to find new applications for knowledge learnt. The traditional approach of unquestioning obedience in the classroom learning, results in students with narrow and less creativity as well as weak innovative thinking.

In many science classes, teachers are always making judgments as to how well a student's response aligns with the textbook's answer because it is simpler to compare an idea to a textbook's answer than questioning students' reasoning that support the answer given by the student (Russ, Coffer, Hammer, & Hutchison, 2009). Furthermore, research conducted by Zohar (2008) found that most of the teachers interviewed believed that trying to teach or infuse reasoning is inappropriate for low-achievement students due to their capabilities. Educators see these students as "stuck" in the early phase of learning as compared to high-achieving students who have mastered the basic skills and better prepared to handle more complex learning tasks. Torff (2006) stated that teachers' beliefs of students achieving level might influence the types of activities conducted. For example, low achieving students might be involved in fewer higher order thinking activities due to teachers' perceptions that they were unable to cope with them. As a result, this restricts their academic growth which in turn makes higher order thinking activities less likely to be used. Similarly, Abdullah Mohd Noor (2009) in his study showed that teachers believe that 'teaching strategies are constraints' and 'a change from memory-based learning to thinking-based learning' was ranked the highest constraint for a teacher to integrate higher order thinking skills (HOTS) among students. Rajendran (2001) found that trained teachers in Malaysia in general find it problematic to infuse higher order thinking skills (HOTS) into classroom instruction effectively. Therefore, most of the time, reasoning which is a higher order thinking skill, is always neglected in a classroom and not emphasized especially among low achieving students. The questions that arise at this point are how can we expect students to have mechanistic reasoning while the classroom instruction does not encourage the integration of higher order thinking skills (HOTS) but rather merely learning the correct answer? More so, is it true that only students who achieve higher grades in Science can be taught higher order thinking skills?

Hence, how high and low achieving students at different ability levels generate mechanistic reasoning would probably need deep investigation to obtain input into the teaching and learning process. As such, this study focused on the need to explore high and low students' mechanistic reasoning in developing coherent understanding of cell biology and to acquire a holistic comprehension of the Theory of Cell.

Rationale of the Study

The cell is fundamental in Biology as the atom is to Chemistry. Truly, everything in an organism occurs fundamentally at the cellular level: from transporting oxygen into red blood cells to providing tensile strength to lift a dumbbell via tendons, ligaments, and muscles, or regulating glucose concentration in the blood via pancreatic regulation of insulin secretion. In today's biological world, students must be able to appreciate and think about life at the cellular level. Why is this so? This is because the study of diseases (like cancer, Alzheimer's, diabetes and sclerosis), epidemics (influenza, AIDS and SARS) or the loss of biodiversity (due to eutrophication of lakes, river and ponds); each requires an understanding of unique cell types and their biology and physiology (McLaughlin & Seaquist, 2008). Similarly, an understanding of the Theory of Cell is central to understanding some of the most important biological phenomena, and offers an opportunity to examine the cellular explanation of these phenomena (Cohen & Yarden, 2009). Thus, in all biology textbooks, the Theory of Cells is taught at the very onset. Various international biology education programmes emphasize the importance of teaching and learning the Theory of Cell at high school level including the National Science Education Standards (National Research Council [NRC], 1996) and the Benchmarks for Science Literacy (American Association for the Advancement of Science [AAAS], 1993).

However, the cell as a theme of study is characterized as difficult to understand by students and numerous students' comprehension difficulties with regards to the Theory of Cell have been reported among school students (Dreyfus & Jungwrith, 1989; Flores, 2003; Lewis et al., 2000; Verhoeff et al., 2008). Cohen and Yarden (2009) recommended that the Theory of Cell should be studied longitudinally to provide an opportunity to investigate how students form meaningful relationships between the various concepts related to the Theory of Cell. Thus, the scope of this study will revolve within the concepts related to cell.

Previous studies have also showed many general and significant problems in the learning of the Theory of Cell and their processes. The problems include difficulties in comprehending the structures and processes that constitute the cell as a living thing (Verhoeff et al., 2008), and students' difficulties in relating biological phenomena with their cellular and molecular explanation (Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000; Verhoeff at al., 2008; Cohen & Yarden, 2009) .The lack of coherent understanding of the cell could be due to a lack of higher order thinking skills (HOTS) such as mechanistic reasoning (Verhoeff et al., 2008). Douvdevany, Dreyfus and Jungwrith (1997) showed that knowledge of students related to the cellular processes lack coherence, although they have specific declarative knowledge of the cell. When searching the cause of a lack of coherency in cell biology, one of the reasons is that students are unable to utilize mechanistic reasoning in explaining biological phenomena. This is supported by Abrams et al. (2001), Metz (1991) and Russ et al. (2008) who commented that mechanistic reasoning is fundamental by which students are able to account for how changes in a biological system occurs. Mechanistic reasoning is also employed recently in medicine to look into the underlying mechanisms and to predict the therapy as well as the relevant effect of a therapy (Howick, Glasziou & Aroson, 2010).

Zohar, Degani and Vaakin (2001) argued that thinking should be applied to all learning and to all learners. Nevertheless, the study by Zohar et al. (2001) showed that 45% (n= 40) of teachers believed that higher order thinking is inappropriate for low-achieving students. This is consistent with findings from the research conducted by Warburton and Torff (2005) and Torff (2006) that teachers favour lower order thinking skills activities over higher order thinking skills (HOTS) for low achieving students. The results suggest that low achieving students may be involved in fewer high order thinking skills (HOTS) activities in schools. Therefore, reasoning is not always given the attention that it should be, either in the normal classroom instruction or among low-achieving students. Gopnik, Sobel, Schulz and Glymour (2001), likewise, stated that even a child should be encouraged to provide a reason in understanding relationship between concepts. Despite much research showing the importance of mechanistic reasoning in assisting students' explaining biological processes, little explicit research has been conducted in investigating students' mechanistic reasoning.

Hence, it is important to assist students to develop mechanistic reasoning throughout the process of learning sciences if producing more adept scientists is the ultimate goal in Science education. This present study is an attempt to study the mechanistic reasoning of high and low achieving Malaysian students. It especially investigates on how students' reason mechanistically and makes sense of the phenomenon.

This in turn can facilitate educators in planning and utilising suitable pedagogy to enhance students' mechanistic reasoning.

Objectives of the Study

Mechanistic reasoning, a high order thinking skill, plays a crucial part in developing the coherency of the mechanisms involved in reasoning. However, this is not being emphasised during classroom learning especially among the low achieving students. Thus, the overall aim of the study was to investigate high and low achieving students' mechanistic reasoning over a specified period of time. Based on this general aim, several specific objectives were put forward. The specific objectives of this study were as follows:

1. To explore mechanistic reasoning among selected high and low achieving Form Four science students for the Theory of Cell;
2. To describe the progression of mechanistic reasoning over a specific period of time among selected high and low achieving Form Four science students for the Theory of Cell; and
3. To determine the emergent representations of mechanistic reasoning among selected high and low achieving Form Four science students.

Research Questions

Mechanistic reasoning is an important skill espoused by scientists in searching and explaining the coherency of certain phenomenon; nevertheless, such reasoning is not given attention in the science classroom to facilitate students in developing a coherent understanding of biological concepts especially among low achieving students. Thus, the research described here addressed some questions related to the problem. The study focused on the following specific questions:

1. How is the emerging mechanistic reasoning among the selected high and low achieving Form Four science students for the Theory of Cell?
2. How is the progression of mechanistic reasoning over a specific time among the selected high and low achieving Form Four science students for the Theory of Cell?
3. What are the emergent representations of mechanistic reasoning among the selected high achieving and low achieving Form Four science students?

Significance of the study

Usually, the concept related to the Theory of Cell in Biology textbooks at secondary and high school level present basic processes of living things as separate elements (Flores, 2003). It is, therefore, difficult to teach a process like respiration that moves from a cellular level to a systemic level. It is also difficult to explain the functioning of diverse organs and organisms if the cell level is detached from other levels of organization. Therefore, this study may signal a possible direction for change in the teaching of Biology.

The incoherency tests developed in this study will be administered to students to obtain data on students' actual understanding for the Theory of Cell. Nonetheless, these incoherency tests can also be used by other educators to identify their students' coherent understanding for the Theory of Cell. The data obtained is useful for educators to help students understand the relationship among the concepts as well as identifying the incoherencies that exist among Form Four science students. Duit (2007) mentioned that progress in understanding and learning science appears only possible if there is a merging between science-oriented and student-oriented perspectives. Hence, investigating existing incoherencies of high achieving and low achieving students (student-oriented) related to the Theory of Cell (science-oriented) might shed some light on the understanding and learning of science.

In view of the science curriculum's current emphasis on the importance of Higher Order Thinking Skills (HOTS) in teaching and learning science in Malaysian classrooms, it is considered timely to venture into as much science cognition research as possible especially with regards to mechanistic reasoning being an important part. Information gathered from this study would provide some insight into the reasoning processes while trying to develop coherent biological understanding related to the Theory of Cell. Besides this, the findings of this study would probably contribute to the area of cognitive psychology in general and science cognition in particular. This could particularly relate to students' learning of biological processes. In the local Malaysian context, based on extensive literature review, it can be noted that research on higher order thinking skills (HOTS) have been mainly focused on critical thinking skills (Lay, 2009; Rajendran, 2001), analogical reasoning (Maria Salih, 2010) and scientific reasoning (Hamizul Hamid & Merza Abbas, 2012; Nor'ain Mohd. Tajudin et al., 2012; Sopiah Adbullah & Adilah Shariff, 2008). Thus far, the researcher could not locate any other research conducted related to mechanistic reasoning locally. As such, this study can be considered an initial step to investigate mechanistic reasoning to achieve coherent understanding of biological processes which students often feel are abstract and face obstacles in learning.

This study has significant implications for educational practice. It is appropriate for educators to provide students at all levels of science instruction with subject matter rich in mechanistic possibilities so that students can practice this kind of reasoning to productively make sense of the physical world.

This study has put great emphasis on the students' mechanistic reasoning in developing coherent comprehension on four biological concepts which are cell structure and organisation, movement of substances across the plasma membrane, chemical composition of the cell and cell division. As reported earlier in the statement of the problem, mechanistic reasoning is fundamental in learning science but which students direly lack. Using mechanistic reasoning could help students to associate biological concepts, which at the present time is compartmentalized in the teaching and learning process. It is hoped that the findings of the present study will shed some light as to how the students relate biological processes to the Theory of Cell. This again, would contribute not only to the growing body of literature in mechanistic reasoning but also in learning biology.

As stated earlier based on extensive review of literature, no studies have been reported related to mechanistic reasoning in teaching and learning science in the Malaysian context. As such, research about the mechanistic reasoning of Malaysian science students in learning biology is still at the beginning stage. This type of research that is argued in the present research should help facilitate the identification and documentation of additional important aspects of mechanistic reasoning among different achievement levels. In addition, it is also hoped that the findings of this study would provide some information as to the effectiveness of the science teaching training programmes especially the science methodology courses, in teacher training colleges and universities. This is in relation to whether the pedagogy of teaching and learning science can be improved. If found to be suitable and appropriate, mechanistic reasoning could be taught as one of the methods of instruction to enhance teaching and learning. In addition, being aware of the process of mechanistic reasoning, the exposure and practice might make future science teachers more prepared, confident and optimistic in teaching difficult and abstract concepts in science among different levels of students.

The in-depth exploration into students' mechanistic reasoning among high and low achieving students would provide valuable knowledge on how mechanistic reasoning would be appropriate and beneficial for them. Teachers would be able to better decide as to how to carry out mechanistic reasoning in their instruction or task especially in giving assistance to low achieving students. Findings from this study could also help science educators to improve their pedagogy and assist students develop coherent comprehension in learning biological processes. Moreover, the findings from this research can be used to promote and support the development of new and more nuanced teaching and learning resources in mechanistic reasoning which is suitable for high and low achieving students. However, not all studies are perfect. Therefore, the limitations of the study are discussed in the following section.

Limitations of the study

Despite the valuable information that can be obtained in investigating students' mechanistic reasoning, there are also some limitations in this study.

First and foremost, there are several topics which are interrelated to cell biology. Yet, only four topics will be chosen to be investigated in relation to students' mechanistic reasoning in this study due to time constraint.

The topics related to the Theory of Cell which are cell structure and cell organisation, cell division, movement of substances across plasma membrane and chemical composition of the cell respectively are introduced in the Form Four Biology syllabus. Thus, the sample chosen are Form Four students. The shortcoming is that, the teaching of these topics will be carried out simultaneously in all schools. Hence, it is impossible for the researcher to be in more than one school at the same period of time. To overcome this predicament, only students in one secondary government school were chosen as the participants in this study. Therefore, whatever findings obtained from this study would only be applicable to similar groups and may not be generalized. The incoherencies identified through many rounds of testing may not be exhaustive. However, the researcher covered as much as possible as time permitted.

The progression and cognitive processes of students' reasoning will only be observed for four topics related to the Theory of Cells. Hence, it may or may not be applicable to other topics in biology. However, the data gained can be generalised within the same context. Further investigation need to be carried out in future to assess students' mechanistic reasoning for other topics or in different contexts so that data obtained will yield more fruitful insight for educators.

Due to the nature of the study which had to be aligned with the Form Four Biology curriculum, students' knowledge about Biology is limited to only the first four topics at the Form Four level. Therefore, the mechanistic reasoning generated by students during the course of the study will not go beyond the topics covered. Thus, in comparison to previous studies in mechanistic reasoning in Science learning, the concepts involved in the present study were basic concepts in Biology. This had to be taken into account when attempting to use the Russ's analytical framework in the analysis of the data and will be explained further in the Methodology chapter.

Students' written tasks in the Living Cell Tool utilised as a teaching tool and a data collecting tool were prepared topically according to the national curriculum. For analytical purposes, the researcher needed to merge students' data (their answers) from each written task individually to gain insight as to how the concept of Cell developed from one topic to another for each student. Hence, this may have made a slight difference in their mechanistic reasoning although the researcher did not make any changes to the students' answers while merging. Nevertheless, the researcher tried to reduce the weakness of the merging by doing participant validation as well as peer review by panel experts. According to the Malaysian Child Act 2001, a child means a person who is under the age of eighteen. Therefore, the participant validation carried out by the researcher among the participants who were under 18 might be subject to their maturity. However, participant validation was still carried out in the study as suggested by Bryman (2001) and Robert, Priest, Traynor (2006) so that researcher bias can be reduced by participant validation. Participant validation refers to the practice when researchers share interpretations and theorise with the research participants to ensure the consistency of the data.

The presence of an observer might have had considerable impact on students' behaviours of those being observed which is known as observer effect. Observer bias and expectation might occur while conducting the research. However, Fraenkel and Wallen (2007) stated that this can be overcome by staying around long enough to get students used to the observer's presence. Thus, this present study involved five months of infusion and the researcher did her best to overcome bias by audio taping and videotaping the teaching process for peer review. In addition, observation by the subject teacher during the infusion of mechanistic reasoning was carried out to minimise the observer bias and expectation. This is further discussed in Chapter 4 Methodology.

Definition of Terminologies

There are some definitions that need to be clarified to avoid any perplexity in this study.

Theory of Cell

The theory of cell in this study focuses on animal and plant cells. The theory of cell in this study is based on the three basic principles put forward by Schwann, 1839 and Rudolf Virchow, 1855 (in Becker, Kleinsmith, Hardin and Bertoni, 2009) but still holds to this day. These principles are,

i. All organisms consist of one or more cells.

ii. The cell is the basic unit of structure for all organisms.

iii. All cells arise only from pre-existing cells.

Thus, the cell is not only the basic unit of structure for all organisms but also the basic unit of reproduction. Understanding of cells and their properties is fundamental to a proper appreciation of all other aspects of Biology. Based on these principles, modern cell Biology involves the weaving together of three different strands – cytology, biochemistry and genetics (Becker, Kleinsmith, Hardin and Bertoni, 2009). Therefore, topics that are related to the theory of cell in the present research context are:

Cell structure and cell organisation

Cell structure and organisation is the first topic in Form Four Biology which is concerned primarily with cellular structure. This topic revolves around what cells are, how they function, general characteristics of cell and the specialisation that cells undergo.

Movement of substances across the plasma membrane

Movement of substances across the plasma membrane is one of the topics in Form Four. In this study, it refers to how cellular membranes control the passage of substances which involve simple diffusion, osmosis, facilitated diffusion and active transport (Campbell & Reece, 2005).

Chemical composition of cell

The chemical composition of cells discusses the structure and function of four main classes of macromolecules which are carbohydrates, proteins, lipids and nucleic acids.

Cell division

The process of cell division is an integral part of the cell cycle (Campbell & Reece, 2005). There are two types of cell division, namely mitosis and meiosis. Both biological processes are just one part of the cell cycle. The Cell cycle involves four stages which are the G_1 phase (first gap), the S phase (synthesis), the G_2 phase (second gap) and the mitotic/ meiosis phase (Campbell & Reece, 2005). In this study, both the cell cycle and cell division are included.

Mechanistic Reasoning

According to Best (1999), reasoning is a high level mental process which involves an information processing chain. Mechanistic reasoning in this study involves entities, the property of the entity and activities that can bring about cause and effect in explaining the coherent understanding between biological processes and the theory of cell. This definition is based on Cummin's (1975) explanation of mechanistic reasoning which is how entities and activities are organised to do something. This explanation has also been adopted by Craver (2001) and Russ et al. (2008). Darden and Craver (2002) put forward that in trying to establish the cause and effect of a phenomenon, first an activity for each entity must be found and vice versa and eventually these entities and activities must be chained. Therefore, in the context of the present study the definition of mechanistic reasoning combines the explanations put forward by Cummin (1975), Craver (2001), Darden and Craver (2002) and Russ et al. (2008) as the starting point. The chaining which indicates cause and effect was then elaborated into configurations and finally into levels of cognitive processing. Each of these will now be defined in turn.

Entities

Entities in the present research refer to the objects that affect the outcome of the phenomenon (Russ, et al., 2008). For example, the nucleus has a *nucleolus* and a *nuclear membrane.*

Property of the entity

Property in the present research refers to the general properties of entities that are necessary for the mechanism to run (Russ, et al., 2008). For example, *the nucleus is made up of a double membrane with a phospholipid bilayer.*

Activities of the entity

Activities of the entity in the present research refer to the actions and interactions that occur among the entities (Russ, et al., 2008). For example, *the nucleus controls cellular activities.*

Links and Chaining

Links in the present research refer to the component, attribute, functional and process links generated by the high and low achieving students in their mechanistic reasoning which indicate cause and effect. The links generated might be accurate or inaccurate. Chaining in the present research refers to the connectivity between the links within a phase and across phases. This will be further discussed in Chapter 5 Analysis of mechanistic reasoning.

Configurations

Configurations in the present research refers to the map generated based on the links and chaining generated by the students. There are three types of configurations, namely linear, spoke and network. Different configurations have different hierarchies and characteristics which will be further discussed in Chapter 5 Analysis of mechanistic reasoning.

Cognitive Processing

Cognitive processing in the present study refers to the types of links, chains and configurations generated as the students progress in their mechanistic reasoning from phase I to phase IV. There are four types of cognitive processing. They are type I and type II simple cognitive processing and type I and type II complex cognitive processing. This will be further discussed in Chapter 5 Analysis of mechanistic reasoning.

Incoherency

Incoherency in this study indicates the inability or inaccuracy of the students in constructing chaining between the entities, the activities and the property of the entity within a topic of the theory of cell as well as across the topics.

Phases

Phases in the present research refer to the topics of the Theory of Cell taught in the school. Phase I refers to cell structure and organisation. Phase II refers to the movement of substances across the plasma membrane. Phase III refers to the chemical composition of the cell. Phase IV refers to the cell division.

Elements

Elements in the present research refer to the structure, organisation and genetics and generation of new cells in each of the four topics in the Theory of Cell addressed in this study.

High and Low Achieving Students

In this present study, the high achieving students refer to those who scored 80 and above in the Science Test constructed by the researcher while the low achieving students are referred to those who scored 40 and below in the Science Test .

Progression

In this present study, progression does not refer to the improvement that occurs among high and low achieving students from phase I to phase IV but rather to explain the students' flow of cognitive processing from phase I to phase IV. Different phases might show different cognitive processing which indicates students' progression.

Emergent Representation

In this present study, emergent representation refers to the learning outcomes of students' overall mechanistic reasoning from the data collected. The learning outcomes reflect the understanding of the students in relation to the Theory of Cell. The emerging representation refers to intuitive, assimilated, transformational and misinterpreted representations.