CHAPTER 7

CONCLUSIONS AND IMPLICATION

Introduction

A vast number of studies have been reported on the importance of mechanistic reasoning in understanding the coherency of the living phenomenon (Janssen & de Hullu, 2008; Jordan, Gray, Demeter, Liu and Hmelo-silver, 2008; Ploger, 1991; Taylor & Jones, 2009). However, most empirical research indicated a lack of explicit investigation into mechanistic reasoning and was investigated over a short period of time. This present study has explored Malaysian Science students' mechanistic reasoning for the Theory of Cell. It also investigated the mechanistic reasoning of two different achievement groups mainly the high and low achieving students. In addition, the patterns of the high and low achieving students were also looked into. Eventually, a comparison between the two achievement groups was conducted to gain a clearer and vibrant understanding of their mechanistic reasoning.

A Living Cell Tool was prepared to probe students' mechanistic reasoning. Interviews and classroom discussions were employed and all participants had to pen their reasoning in completing the activities in the task. Interviews and classroom discussions were recorded to gain insight into their reasoning written in the tasks. The data collected helped to construct the patterns of the reasoning for The Theory of Cell. It is hoped that this study would be an eye opener to reveal how science students use mechanisms in their reasoning to conceptualise and chain the cause and effect through various concepts across several topics in developing their own Theory of Cell.

Summary of Findings

Students' incoherencies for the Theory of Cell were collected through four incoherency tests (each topic for one incoherency test). The analysis of the incoherency tests were used to consolidate the Living Cell Tool.

Based on the first incoherency test which is related to cell structure and cell organisation, students indicated less incoherency as compared to other topics. The majority of the incoherencies that arose, were related to the organelles and the processes that take place in the organelles such as cell specialisation, protein and lipids synthesis.

More incoherencies were found for the second topic which is movement of substances across the plasma membrane as the students needed to relate this to multiple concepts within the topic. Students encountered more difficulties when they had to tie up concepts like structure of the plasma membrane, properties of the substances and types of movement together.

Students had more incoherencies in the third topic which is the chemical composition of the cell as compared to the previous two concepts. The majority of incoherencies arose from the structure of organic compounds and enzymes. The reason chosen by the students was not consistent with the chosen content knowledgemost of the time.

The last topic that was explored for students' incoherency was cell division. This topic had the most incoherencies among the four topics. Students encountered more difficulties when dealing with meiosis than mitosis items. The overall analysis also showed that students were able to select the accurate content knowledge but failed to support them with an underlying reason. For example, most of the students were able to relate cell division to the genetic constitution or number of chromosomes produced; yet, the reason revealed their incoherencies about the concept of mitosis and meiosis in different types of cell.

Based on the analysis of students' incoherencies, the Living Cell Tool was constructed and carried out to gain students' mechanistic reasoning. The researcher undertook a robust method of analysis by organising their data, scrutinising the links, chaining and configurations generated by high and low achieving students to determine their cognitive processing for their mechanistic reasoning. Mechanistic reasoning is probably a new experience encountered by the participants of this study. Therefore, at the beginning of this study, all the high and low achieving students only managed to achieve either Type I or Type II simple cognitive processing. Some links were inaccurate and no chaining or invalid chaining was formed between the elements. As they proceeded to the second, third and fourth phases, their mechanistic reasoning indicated Type I or Type II complex cognitive processing.

As for the second research question, which is the progression of students in mechanistic reasoning over time, some high and low achieving students indicated steady progression whilst some indicated unstable progression in their mechanistic reasoning. All the high and four low achieving students demonstrated steady progression while two low achieving students demonstrated unstable progression. This indicated that even the low achieving students were able to demonstrate the same progression as the high achieving students. Students with steady progression began with either Type I or II simple cognitive processing. They managed to move up to either Type I or II cognitive processing and sustain at that level as they proceeded to phases II to IV. Only two high achieving students were able to achieve Type II cognitive processing and maintain it at that level.

There were two low achieving students with unstable progression who were able to achieve type II complex cognitive processing but failed to maintain that level of cognitive processing as compared to two high achieving students who demonstrated type II complex cognitive processing in steady progression and able to maintain the level of cognitive processing. Based on the findings, high achieving students performed better as they generated more accurate chaining between the elements as well as across phases; however, low achieving students also demonstrated that they had the ability to achieve type II complex cognitive processing. Furthermore, based on the data, not all high achieving students were able to achieve type II complex cognitive processing.

As mentioned above, both high and low achieving students were classified at the same level in the beginning of the infusion of mechanistic reasoning and showed progression in the following phases. This indicated that infusion of higher order thinking skills, such as mechanistic reasoning, require proper guidance even among the high achieving students. The findings also suggest that low achieving students would be able to cultivate higher order thinking skills perhaps over a longer period of time.

Generally, high and low achieving students showed not much difference in their mechanistic reasoning based on the findings. This suggested that low achieving students, despite constructing invalid chaining, were actually capable of reasoning mechanistically. This is also probably due to the tasks and prompting questions given by the teacher that triggered them to perceive the chaining from task to task. This indicated that infusion of mechanistic reasoning among low achieving students is possible with proper prompting and guidance. In addition, some low achieving students’ mechanistic reasoningwas as good as some of the high achieving students.As postulated by Craik and Lockhart’s (1972) Levels of processing, the ability to construct semantic association (chaining) is crucial for learners to advance to type II processing. In order to construct semantic association, one must attend to the meaning of what he/she has previously learned. Without this, the knowledge will only maintain at Type I processing which will slowly decay or be forgotten.

When students' mechanistic reasoning was further inspected, there were several outcomes revealed which are known as representations in this study. These are intuitive, assimilated, transformational and misinterpreted representations. Some students' mechanistic reasoning indicated intuitive representations when their reasoning was solely based on their assumption and without scientific based explanation. Assimilated representations were further divided into simple and elaborated assimilated representations. A simple assimilated representation is when students are able to assimilate their prior knowledge or newly learned information without further elaboration. In contrast, students were not only able to assimilate the information but also extended their reasoning by elaborating in elaborated assimilated representations. Elaborated assimilated representations can occur within a phase or across phases. Students' mechanistic reasoning, sometimes, could be inaccurate. However, as they proceed to the following phases, their mechanistic reasoning could be transformed and replaced by a more precise one. This outcome is known as transformational representations which can be observed across the phases. Last but not least, students' might not accomplish accurate mechanistic reasoning all the time. On certain occasions, they might misunderstand the knowledge that they have learnt which was revealed in their mechanistic reasoning. These types of representations are known as misinterpreted representations. The implications of the study are given in the following section.

Implications of the Study

The implications of this study were drawn after considering the constraints and limitations discussed in Chapter 1. There have always been questions that arose as to why science students often compartmentalised the learning of Science and why low achieving students were not suited in learning the art of higher order thinking such as reasoning? Having entered a new era of advancement in Science education especially in the field of cognition, all units should collaborate towards the change in teaching and learning of Science especially with regards toabstract Biology concepts. As such, several practical implications for the teaching and learning of a similar Biology concept in classrooms can be drawn from the findings in this study. This is because learning an abstract concept in Biology is highly dependent on the guidance provided throughout the teaching and learning process. This in turn leads to the attainment of the goal of science education which is to yield students who are equipped with high order thinking skills such as reasoning.

Numerous studies have pointed out students' learning difficulties related to the Theory of Cell (Barman and Stein, 2008; Cohen and Yarden, 2009; Flores, 2003; Lazarowitz and Lieb, 2006; Lewis et al., 2000c, Marbach-Ad and Stavy, 2000; Riemier and Gropengieβer, 2007; Saka et al.,2007 and Wang, 2007). Students fail to assimilate the Theory of Cell to cell processes due to a lack of higher order thinking such as mechanistic reasoning (Taylor and Jones, 2009). Similarly, Lewis and Kattmann (2004) stated that students who fail to recognise the mechanisms (mechanistic reasoning) in the process consequently have little awareness of the relationship across biological processes. Findings from this study also supported the previous findings and these findings might help educators to identify the activity designed for the students to infuse mechanistic reasoning based on the incoherency for the Theory of Cell.

Previous findings found that teachers believe low achieving students were unable to reason due to their capability (Torff, 2006; Warburton &Torff, 2005; Zohar, Degani, & Vaakin, 2001; Zohar & Dori, 2003). However, this present study shows that high and low achieving students were able to generate mechanistic reasoning although low achieving students might encounter more difficulties and require longer time than high achieving students. It can be suggested that low achieving students could be provided more classroom opportunities to engage in higher order thinking skills over a prolonged period of time. They are not only able to perform these higher order thinking skills in constructing their reasoning, but at the same time are able to challenge and understand the Theory of Cell.The findings of the previous studies and the present study might imply that science teachers should be able to teach mechanistic reasoning without worrying about students who are incapable of coping with it.

Ganeshadeva (2011) stated that students in Malaysia are not taught 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 classroom learning results in students with narrow and less creativity as well as innovative thinking. Rajendran (2002) also pointed out that even teachers who are trained find it difficult to infuse higher order thinking skills such as mechanistic reasoning. In this present study, it seems possible to introduce mechanistic reasoning by using the Living Cell Tool to all levels of students in the local context since the findings from this study seem to show that all the students manage to link, match, elaborate and chain throughout the reasoning process. The tool might act as a reference for educators on what types of activities might help students to generate mechanistic reasoning. Based on previous and present findings, thismight imply that it is important to also provide continuous training for pre-service and in-service science teachers to infuse mechanistic reasoning in the science classroom.Furthermore, higher order thinking skills can be cultivated at an early phase in order to yield fruitful results. The interaction observed among the high and low achieving students in the span of completing the tasks as well as prompting by the teacher during classroom discussions can also imply that mechanistic reasoning is probably possible, practical and maybe productive with proper planning and guidance which is described in the Living Cell Tool.

Based upon the Investigative Learning Theory (Engeström, 1994), Vygotsky's Zone of Proximal Development and Levels of Processing (Craik and Lockhart, 1972), the process of reasoning that was explored among high and low-achieving students could provide a guide to teachers, textbook authors as well as students on how learning can be effective instead of just emphasising on exam-oriented questions and facts. The cognitive processing of students' mechanistic reasoning could also be useful to teachers who wish to encourage their students to be involved in the learning task.

The representations of mechanistic reasoning could serve as a reference on how low and high achieving students generate reasoning. Past research such as research from Craver (2007) and Sloman and Fernbach (2011) have shown that representations are mainly arranged in a hierarchical order. However, in the present study, the representations did not show any particular order. Both high and low achieving students encountered the four representations as they learned each new topic. By allowing students to experience activities which require high order thinking skills (such as mechanistic reasoning), it gives them the opportunity to recognise, match, link, extend and chain the mechanisms in their reasoning and proceed towards a deeper level of processing. Teaching students to perceive the connectivity of the Theory of cell is crucial, thus mechanistic reasoning could help students to make sense of their understanding by identifying the mechanisms involved in their reasoning. Once they have made associations between the mechanisms in their reasoning, the teacher can challenge the students' reasoning so as to assist students to think profoundly.

Biology is, often perceived by the majority of students, as a subject that requires a lot of memorisation. To inculcate mechanistic reasoning in understanding Biology might help students to discover that more mechanisms are involved in their reasoning and create interest in the learning of Biology. The interaction between the teacher and the students would lead to a more meaningful learning experience.

Because of its vital role for HOTS, it seems appropriate to introduce mechanistic reasoning as a pedagogical content knowledge (PCK) in teacher training colleges. In this way, teachers could be trained to conduct mechanistic reasoning in class and engage students to use in them the learning process. In addition, this study might aid teachers to transform their beliefs of engaging low achieving students in high order thinking skills as this study revealed that low achieving students are also able to reason and their chaining expanded as they proceed in the long run. It is hoped that the discussion reported in the present study can inspire science teachers to infuse mechanistic reasoning in their classrooms. In addition, the utilisation of atool, which is similar to the Living Cell Tool in different levels of education and different subjects, could be created.

About the implications for scholars and researchers, the analysis steps of the present study has expanded beyond Russ's et al. (2008) analytical framework for the analysis of mechanistic reasoning. The analysis was found practical and useful in the present study in evaluating students' mechanistic reasoning. This method of analysis could possibly be used by future researchers to explore students' mechanistic reasoning by identifying the links, converting the links into configurations, analysing the types of configuration, identifying the chaining generated and eventually categorising students' mechanistic reasoning into four different cognitive processing. Teachers could also employ these cognitive processing to assess students' mechanistic reasoning, to identify links and chaining generated by students in the science classroom. The suggestions for future studies are outlined in the following section.

Contribution and Significance of the Study for Practice

In order to prepare the Living Cell Tool, several steps proposed in this study can be pursued. Most importantly the construction of the incoherency tests before preparing the Living Cell Tool. This is because the incoherency tests could reveal the "missing chaining" within a topic as well as across the topic. Teachers could use this data to design a task that gauges students' mechanistic reasoning in understanding the interrelation of the topics. The summary of the steps in Figure 7.1 could be used as a guide to prepare the Living Cell Tool.

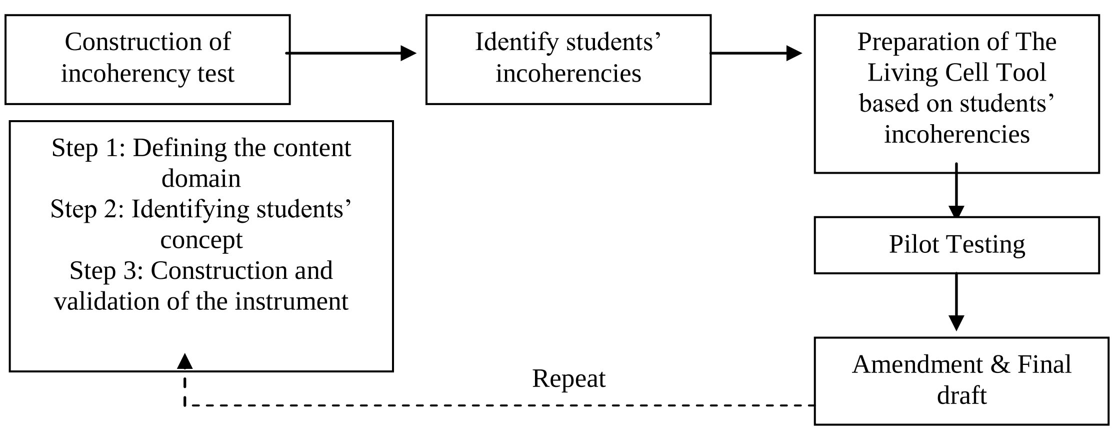

Figure 7.1. Flow to Prepare the Living Cell Tool

The rubric put forward for the four levels of cognitive processing could be utilised by the teachers to identify weaknesses in students' mechanistic reasoning and provide proper guidance to students. Furthermore, teachers could trace students' progression over time by using the cognitive processing levels proposed by the researcher. Students with unstable progression could be identified and further guidance could be given for the topic that students encountered difficulties in developing the chaining for cause and effect.

Suggestions for Future Research

Based upon the conclusions discussed in this study, several suggestions are recommended for future research in this area.

Research in mechanistic reasoning is still considered at the foetal stage. Thus far, mechanistic reasoning research has mainly focused on the importance mechanistic reasoning (Abrams et al., 2001; Craver, 2001; Glennan, 2002; Janssen and de Hullu , 2008; Jonassen and Ionas, 2008; Southerland et al., 2001 and Thagard, 1998), strategies of mechanistic reasoning (Craver, 2001; Darden and Craver, 2002 and Machamer et al., 2000) and recently Russ et al. (2008) had proposed an analytical framework to analyse students' mechanistic reasoning. As such, a replication of this study using different biological concepts such as the digestive system or transport system in humans could be conducted to explore students' mechanistic reasoning of the Theory of Cell with the biological concepts. This could provide a wider and in-depth study of how students generate mechanistic reasoningto integrate the Theory of Cell into biological processes. Besides that, this could also probably enhance and strengthen the analysis method postulated in Chapter Five.

Some research showed that high achieving students performed better in higher order thinking tasks (Cook et al., 2008; Simons and Klein, 2007; Thomas and MacGregor, 2005) while some research showed otherwise (Lay, 2009; Wu and Tsai, 2004). The findings of this present study showed that high and low achieving students can perform mechanistic reasoning for the Theory of Cells in the long run. The incongruity in these research suggest that similar research should be carried out on different samples which could consolidate the patterns of high and low achieving students' mechanistic reasoning. This might reveal the underlying reason to the researchers of the contradiction that occurs in the existing literature. A different sample from different area (rural and urban) might also provide different perspectives of high and low students' mechanistic reasoning.

A similar study could also be conducted with students working in groups instead of individually to explore more about the effect of social construction in assisting students to construct their mechanistic reasoning. The tracing of development in students' reasoning might shed some light to us on how students learn and in what conditions students learn better. A comparative study of students' mechanistic reasoning in groups and individually could also be conducted to gain more insight.

Since this study was only conducted for five months for the Theory of Cell, future studies could look into students' mechanistic reasoning over a longer period of time which would benefit the researcher and educators in tracking students reasoning construction. How much can low achieving students benefit from mechanistic reasoning over a longer period of time also depends on the guidance from the teachers in helping them develop the skills. Therefore, a more in-depth study could be carried out to reveal the types of guidance which are needed to facilitate the reasoning process.

In summary, there are several questions which can be explored explicitly in future research. Specifically, the need to study high and low achieving students' mechanistic reasoningin a broader aspect and different concepts related to the Theory of Cell, the extent to which theirmechanistic reasoning could possibly be established and sustained, as well as developing better support for students to engage effectively in mechanistic reasoning. The researcher concludes the present study in the following section.

Conclusion

A main conclusion that the findings of this study suggest is that cultivating mechanistic reasoning among a low achieving group of students is not an impossible mission. 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. In the present study, high achieving students generated simple cognitive processing in the beginning of the infusion which was similar to low achieving students. Both high and low achieving students progressed to complex mechanistic reasoning as they proceeded along the phases. The overall progression also indicated that both high and low achieving students might encounter steady or unstable progression. This means that both high achieving students are not necessarily always successful in generating stable progression in their mechanistic reasoning. However, the study has suggested that high achieving students might be more capable of maintaining their reasoning at the higher level of complex cognitive processing.

Findings also showed that students' understanding can be transformed. This can be achieved through proper guidance and scaffolding. Students' representations (understanding) of the cell might not be accurate most of the time as they might understand the concept differently from the scientific point of view as was found in the incoherency tests. However, it is important for an educator to identify these representations in order to remedy these students' misinterpretations. Infusion of mechanistic reasoning is a long term process which requires proper preparation as was done in the Living Cell Tool. Teachers could use the tool as a guide and design their own teaching resources to support the infusion of mechanistic reasoning which eventually bring about transformation of students' understandings.

Finally, the present study has shown that Biology is not a subject that should be learnt by mere memorisation. Biology is also not a subject that should be taught in isolation for each chapter. Based on the findings, it appears that mechanistic reasoning is crucial in assisting students recognise the chaining among the concepts in different chapters. This could be helpful for students to perceive Biology concepts as a whole. In short, the study suggests that if mechanistic reasoning can be a more prominent helpful feature in biology classrooms the learning of Biology could be more meaningful.