CHAPTER 5

ANALYSIS OF MECHANISTIC REASONING

Introduction

The process of analysing students' mechanistic reasoning for the Theory of Cell was a tough mission as the data collected for over five months was overwhelming. The obstacles faced by the researcher in analysing the data and how they were solved slowly but surely will be discussed in the following section.

If qualitative research is to yield meaningful and useful results, it is important that the materials under scrutiny is analysed in a methodical manner. The analysis process for the study of students' mechanistic reasoning for over five months and across four topics to determine the underlying mechanistic reasoning that reflected the cause and effect as well as the sophistication of the connectivity and the continuum of students' reasoning became a challenge. The struggle to portray the mechanistic reasoning of each student at the end of five months for the Theory of Cell was amplified as all the sources of data had to be carefully put together to solve the puzzle. Eventually after several attempts of employing different ways of analysis, the stages involved to uncover students' mechanistic reasoning were identified. The stages will be discussed now.

Analysis of Students' Mechanistic Reasoning

The data from each activity in the Living Cell Tool were collected over 5-6 months. Thus, the tool served as an instrument to infuse mechanistic reasoning as well as to collect data. Observations during the study were audio and video taped to probe in-depth responses and capture the rich data pertaining to students' mechanistic reasoning and the generation of reasoning. It was also hoped that the data from the observations would help to make transparent the mechanistic reasoning of students. Observations and interviews helped to support and triangulate the data obtained from the students' written descriptions of their mechanistic reasoning. Several abbreviations are used in the presentation of data analysis, for instance,

R - Researcher

L - Low science achieving student

H - High science achieving student

Phase in the contest of the present research refers to the topics taught from January to May which had to be aligned with the Form Four Biology curriculum specification of Biology. Table 5.1 indicates the phase and topics in the present research context.

Table 5.1

The Phases and Topics in the Context of the Present Study

Phase	Topic
I	Cell structure and organisation
II	Movement of substances across the plasma membrane
III	Chemical composition of the cell
IV	Cell division

Students' mechanistic reasoning revolving around the Theory of Cell was dispersed as the tasks were administered according to the sequence of the national curriculum as it was slowly completed in the classroom. For instance, the topic 'Movement of Substances across the Plasma Membrane' comprised several tasks (such as building a cell model, osmosis application and absorption in the small intestines) to probe students' mechanistic reasoning about the cellular structure. Figure 5.1 shows an example of how a high achieving student (H4) has answered for different tasks for the above mentioned topics.

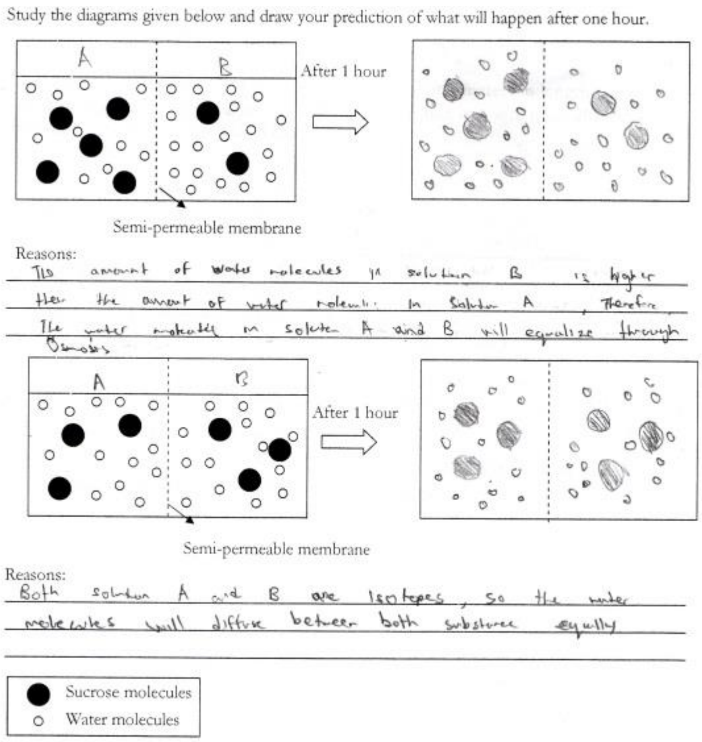
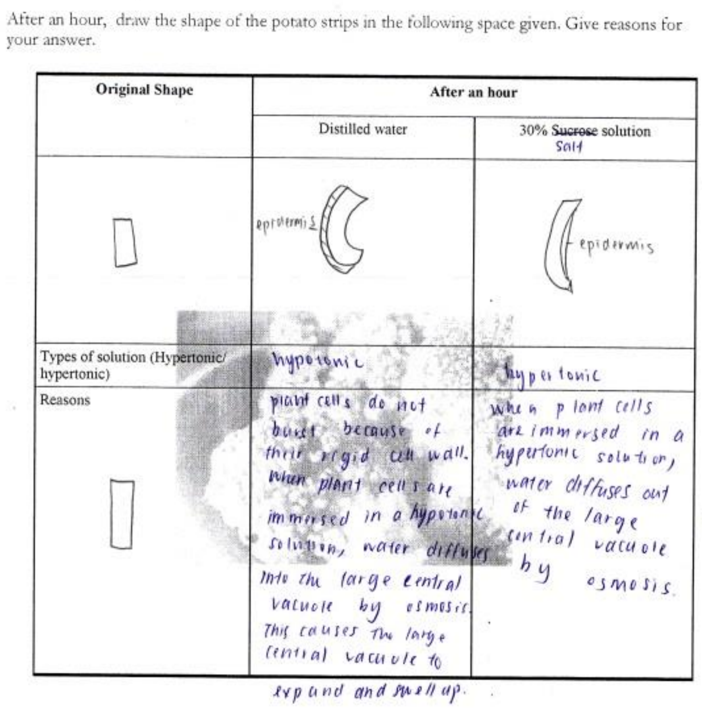
<table>
<tr><th>Task</th><th>Topic</th></tr>
<tr><td>
</td><td>Student's written task for one of the concepts in the second topic - Movement of substances across the plasma membrane (Task 3 Chapter 2 Movement of substances across the plasma membrane, Osmosis concept)</td></tr>
<tr><td>
</td><td>Student's written task for one of concepts in the second topic - Movement of substances across the plasma membrane (Task 4 Chapter 2 Movement of substances across the plasma membrane, Osmosis in plants).</td></tr>
</table>

Figure 5.1. H2's mechanistic reasoning in different tasks for the topic 'Movement of Substances across the Plasma Membrane'

It was time consuming for the researcher to sort out the sequence of reasoning for the Theory of Cell from topic to topic for each student. For example for the topic 'Movement of Substances across the Plasma Membrane', the researcher had to merge in sequence the written data from the two tasks showed in Figure 5.1 in this topic to map out students' actual reasoning for the concept of osmosis. Hence, H2'S final written data for the concept of osmosis was

The amount of water in B is higher than the amount of water molecules in A. Therefore, the water molecules in solution A and B will equalize through osmosis. When both solution A and solution B are isotopes, so the water molecules will diffuse between both substances equally (Written answer for Task 3). Plant cells do not burst because of their rigid cell wall. When plant cells are immersed in distilled water, water diffuses into the large vacuole through osmosis. This causes the large central vacuole to expand and swell up. When a plant cells are immersed in a hypertonic solution, water diffuses out of the large central vacuole through osmosis. (Written answer for Task 4)

(Example of merging H2's written data for concept of osmosis)

Apart from sorting out the students' reasoning for each topic, the researcher also had to uncover how the students understood the cause and effect and how they connected between topics. For example, the task that addresses the sub-concept of cell specialisation in the first topic (cell structure and organisation) was connected to the sub-concept of absorption of nutrients in the small intestine in the second topic (movement of substances across the plasma membrane) as shown in Figure 5.2.

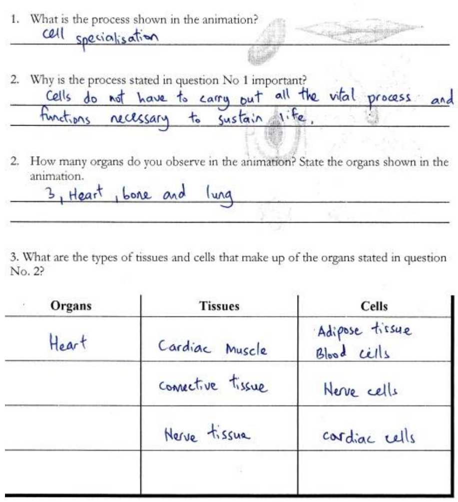
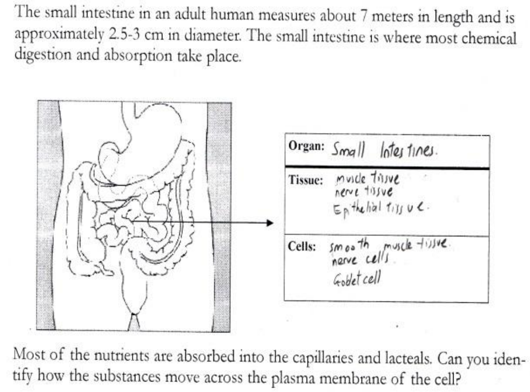
<table>
<tr>
<td>Cell specialisation (First topic: Cell structure and organisation, Task 3)</td>
<td>Absorption of nutrients in the small intestine
(Second topic: Movement of substances across the plasma membrane, Task 6)</td>
</tr>
<tr>
<td>
1. What is the process shown in the animation?
cell specialisation
2. Why is the process stated in question No 1 important?
Cells do not have to carry out all the vital process and functions necessary to sustain life.
2. How many organs do you observe in the animation? State the organs shown in the animation.
3, Heart, bone and lung
3. What are the types of tissues and cells that make up of the organs stated in question No. 2?
Organs / Tissues / Cells
Heart / Cardiac Muscle / Adipose tissue, Blood cells
 / Connective tissue / Nerve cells
 / Nerve tissue / cardiac cells</td>
<td>
The small intestine in an adult human measures about 7 meters in length and is approximately 2.5-3 cm in diameter. The small intestine is where most chemical digestion and absorption take place.
Organ: Small Intestines.
Tissue: muscle tissue, nerve tissue, Epithelial tissue.
Cells: smooth muscle tissue. nerve cells, Goblet cell
Most of the nutrients are absorbed into the capillaries and lacteals. Can you identify how the substances move across the plasma membrane of the cell?</td>
</tr>
<tr>
<td>Description: In phase I (First topic: cell structure and cell organisation), the student was able to identify different types of cells that made up the heart such as cardiac muscles, connective tissues and nerve tissues.</td>
<td>Description: In phase II (Second topic: movement of substances across the plasma membrane), the student was able to identify different types of cells that made up the small intestine such as muscle, epithelial and nerve tissues.</td>
</tr>
</table>

Figure 5.2. The connectivity of H3's written tasks across the topics

Thus, the researcher had to first merge and arrange the students' written tasks to show the sequence of students reasoning from phase I (topic one) to phase IV (topic four) since the mechanistic reasoning tasks were sequentially according to the topics. It must be stated here that the researcher did not manipulate the data by selecting and sequencing the data (students' answers) as desired; conversely, the researcher arranged the data sequentially following the order of the written tasks given to the students from the Living Cell Tool. A similar process was utilised by Thomas (2003) and Gibbs (2007). Interview and classroom observation transcriptions were also utilised to support the written data. For example, with reference to task 3 of the topic cell structure and cell organisation, student

H3's reason was that the cells divide uncontrollably due to something wrong with the cell. During the classroom discussion, he further clarified his reasoning as shown in the excerpt below.

R : How do cells divide uncontrollably?
H3 : There is something wrong with the cell.
R : What do you mean by something wrong with the cell?
H3 : Hm…I don't know. Maybe like human, suddenly goes crazy
(Excerpt from classroom discussion, Cell Division, Task 3)

Based on the student H3's written task, student H3 gave a vague reasoning for cells divided uncontrollably, that is, due to something wrong with the cell. During classroom discussion, the researcher asked clarification from the students. Yet, student H3 was unable to give valid mechanisms in his reasoning. Therefore, the classroom observation transcript is important to cross check on students' written task.

After all the data had been organised, the analysis of students' mechanistic reasoning began. However, challenges arose in trying to figure out the mechanistic reasoning. Firstly, the researcher had collected enormous amount of data throughout the five months of the data collection process. It was not easy to analyse the data for mechanistic reasoning even after the organisation of the data in sequence through the phases. The researcher realised that the analysis would involve more than coding and categorising the data into themes. After a lot of discussion and arguments between a qualitative analysis expert from one of the local universities and peers (two PhD researchers who had experience in qualitative study), the stages of the data analysis were finally established, which will be discussed in the following section.

Step 1: Dividing the Data According To the Principles for the Theory of Cell

As this research explored students' mechanistic reasoning for the Theory of Cell, the topics were cell structure and organisation, movement of substances across the plasma membrane, chemical composition of cells and cell division according to the Biology Form Four Curriculum. Based on the principles for the Cell Theory, which has also been discussed in Chapter 1, each topic was divided into three elements. The three elements were structure, organisation and genetics after discussion with the same panel of a qualitative analysis expert from one of the local universities and peers (two PhD researchers who had experience in qualitative study). Table 5.2 indicates the elements and the respective tasks in the Living Cell Tool in the present research context.

Table 5.2

The Elements and Its Respective Tasks in the Living Cell Tool in the Present Research Context

Element	Example of tasks in the Living Cell Tool
Cell structure and organisation	
Structure	• Cell structure
Organisation	• Cell organisation and specialisation
Genetics	• Genetics composition of different types of cell
Movement of substances across the plasma membrane	
Structure	• Structure of plasma membrane. • The types of movement across the plasma membrane: osmosis, simple diffusion, facilitated diffusion and passive transport
Organisation	• Transport of nutrients in small intestine • Preservation of food • Wilting of plants

Table 5.2 (Continued)

Chemical composition of the cells.	
Structure	• Structure of carbohydrate, protein, lipids and water • Condensation and hydrolysis process
Organisation	• Chemical composition of different organelle • Enzyme synthesis process • Enzyme characteristics
Cell division	
Structure	• Mitosis and meiosis process
Organisation	• Cloning • Chromosomal number of different types of cells. • Formation of different types of cell.

An example of how students' data was categorised according to the elements is shown in Table 5.3.

Table 5.3

Categorisation of Students' Written Task According to Its Respective Elements

Topic	Element	Student reasoning
Cell structure and organisation	Structure	*H1 : It (protein synthesis) starts at the ribosome because ribosomes synthesise protein. Then, it will be sent to RER. RER transports protein to the golgi apparatus. The golgi apparatus will modify, package and transport it out of the cell in secretary vesicles.* *(H1's written task 2)*
	Organisation	*H4 : Sperm needs energy to swim to the ovum. Thus, mitochondria are found abundantly as mitochondria provide energy. Same as the muscle cells which are involved in movement. In metamorphosis of a tadpole, lysosome is needed because it can digest organelle and replace the tail.* *(H4's written task 4)*
	Genetics	*L2 : muscle cells and liver cells have different genetics information because they are different types of cells.* *(L2's written task 3)*

A full data for student H1 is given in Appendix I.

Step 2: Coding the material

After dissecting the text according to the principles of the Cell Theory which are 'structure', 'organisation' and 'genetics', the coding of students' mechanistic reasoning began. This was done by coding each individual participant's data set by referring to Russ's et al. (2008) analytical framework. Since some coding by Russ's et al. (2008) were not applicable in certain tasks, for example students' mechanistic reasoning in genetics, it did not involve the code 'identifying set-up condition' and 'identifying organisation of entity' as shown in the written tasks below.

Example 1

L2 : Muscle cells and liver cells have different genetics information because they are different types of cells (IPE).

(L2's written task 3
Element: Genetics and generation of new cells, Topic: Cell structure and organisation)

Example 2

H1 : The genetics of nerve cells and liver cells (IE) are similar because after fusion between the sperm and ovum (IA), they under mitosis (IA) to form different types of cells. Mitosis produces genetically identical cells (IPE). So, the genetics are similar.

(H1's written task 3
Element: Genetics, Topic: Cell division)
(IPE, IA, IE – refer to Table 5.4)

As shown in the written task above, the codes 'identifying organisation of entity' and 'identifying set-up condition' were not applicable in analysing the written tasks. Similarly, those codes were not detected in students' mechanistic reasoning for the topic 'chemical composition of the cell'. This was because as stated earlier the Form Four curriculum is basic Biology and the two codes from Russ's framework could not be applied. Therefore, the researcher and the same panel of the qualitative analysis expert from one of the local universities and the two peers concurred to exclude the two codes. Hence, the 4 major codes that were utilised from Russ's et al. (2008) analytical framework which is shown in Table 5.4. With these four codes the analysis of mechanistic reasoning focused on the chaining between concepts which gave insight into the cause and effect.

Table 5.4

Russ's et al. (2008) Analytical Framework in Analysing Mechanistic Reasoning

No	Mechanism	Description and Example
1	Identifying Entities (IE)	Students identify objects that affect the outcome of the phenomenon. For example: A nucleus has *a nucleolus* and *a nuclear membrane*
2	Identifying Activities (IA)	Students articulate the actions and interactions that occur among the entities For example: *The* nucleus *controls cellular activities*
3	Identifying Properties of Entities (IPE)	Students articulate general properties of entities that are necessary for the mechanism to run. For example: Mitochondria are *made up of a double membrane*.
4	Chaining	Students reason about one stage in the mechanism based on what is known about other stages in the mechanism. For example: The chemical compositions of mitochondria are protein and lipid as they comprise of membrane. *The* membrane is made up of *a* phospholipid bilayer.

The full data from the tasks across the phases for each student (Appendix J) were dissected, classified and organised according to these codes. For example,

H1 : A nucleus has a nuclear membrane and a DNA (IE).
A Membrane is made up of phospholipids
and transport protein (IPE). } *Chaining*
So, the organic components are lipids and protein (IPE).
Same as mitochondria, it has a membrane (IPE) and the organic compounds that are involved are lipids and protein (IPE). A cell wall is rigid (IPE) as it is made up of protein and lipid (IE). A vacuole has tonoplast (IE) which is the membrane (IPE). It is made up of lipids and protein. Chloroplast has a double membrane (IPE). It is also made up of lipids and protein. The Golgi body is a stack of layers (IPE).

(H1's written task
Element: Organisation, Topic: Chemical composition of cells)

The coded data was verified by the same panel of a qualitative analysis expert from one of the local universities and two peers. The discrepancies that arose were discussed until a consensus was reached. A full detail from a student's mechanistic reasoning (H1) which was coded by using Russ's et al. (2008) analytical framework is given in Appendix K.

Step 3: Identifying the links

As the coding was identified, the text segments were scrutinised repeatedly to extract the links generated by the students. In order to identify the links, the researcher tried to organise the data by creating a visualisation table, an idea derived from Creswell (2008). This is shown in the following written task and Table 5.5.

<u>Example 1</u>

H4 : A nucleus has a DNA, a nuclear membrane and a nucleolus

(IE).The nucleus controls the cellular activities (IA).Mitochondria have a double membrane (IPE) and is made up of cristae and matrix (IE). They generate energy for the cell.

(H4's written task Element: Structure, Topic: cell structure and organisation)

Table 5.5

Visualising Table for H4's Mechanistic Reasoning for Structural Element in Phase I (Cell Structure and Cell Organisation)

Elements	Cell structure and organisation (Phase I)		
	Entity	**Activity**	**Property**
Structure	Nucleus →	controls all cellular activities	
	↓ nucleolus, DNA, nucleus membrane		
	Mitochondria →	generate energy	have a double membrane.
	↓ matrix and cristae.		
	Ribosome →	synthesise protein ↑	
	RER →	Transports protein ↕	Consists of ribosome.
	Golgi apparatus →	Process, package and transport protein out of the cell. ↓	Layers of curve structure
	SER →	Synthesise lipid	Without ribosome

→ Links

From the Table 5.5 constructed for each student, their mechanistic reasoning became clearer by the links between the entities, activity and property. After rigorously comparing the visualisation tables among high and low achievers as well as debating with the same panel of peers and qualitative expert, different types of links were identified. Eventually, four types of links emerged from students' data. How these four categories of links – component links, attribute links, functional links and process links - emerged is shown in the following example. The data was coded by the researcher and reviewed by the same panel members. The discrepancies that arose were discussed until a consensus was reached.

Example 1

H2 : A Nucleus has a nuclear membrane and a DNA(IE). The membrane is made up of phospholipids and transport protein (IPE). So, the organic components are lipids and protein (IE). Same as mitochondria, they have a membrane (IPE) and the organic compounds that are involved are lipids and protein (IE). A cell wall is rigid (IPE) as it is made up of protein and lipid (IE). A vacuole has tonoplast (IE) which is the membrane (IPE)…

Component

Attribute link

(H2's written task
Element: Structure, Topic: cell structure and organisation)

It emerged from the data that some students generated links between several entities such as 'nuclear membrane', 'DNA' and 'tonoplast'. Therefore, the research categorised this as <u>component links</u> whenever students tried to link to the entities in their reasoning. In certain occasions, students also linked properties in their reasoning such as 'rigid', 'double membrane' and 'membrane is made up of phospholipid bilayer'. These describe the character or property of the entity which were named as <u>attribute links.</u> Example 1 shows 2 types of links which are component and attribute links.

Example 2

H4 : A Nucleus has a DNA, a nucleus membrane and a nucleolus (IE). The nucleus controls the cellular activities (IA). Mitochondria have a double membrane (IPE) and is made up of cristae and matrix (IE). They generate energy for the cell (IA).

Component link

Attribute link

Functional link

(H4's written task
Element: Structure, Topic: cell structure and organisation)

In example 2, it can be seen that students generated links between the entity and its activity. These activities indicated the function or action of the activity such as 'nucleus controls cellular activity' and 'mitochondria generate energy for the cell.' This was categorised as functional links in the present research context.

Example 3

Attribute link

L1 : The soil becomes dehydrated when more fertiliser is added (IPE).
Water moves out from the plant (IA) by osmosis (IA) because
The plant has higher water concentration. Finally, the plant wilts (IA).

Process link

(L1's written task
Element: Organisation, Topic: Movement of substances across the plasma membrane)

When students identified different activities in their mechanistic reasoning to explain a process, this was categorised as a process link. Example 3 shows a process link connected to the movement of substances across the plasma membrane.

An example of a student's mechanistic reasoning with the links generated based on Russ at al. (2008) analytical framework is shown in Appendix L.

Step 4: Converting the links into configuration

Although the types of links had been identified, the chaining among these links was not visible. The researcher met another challenge in analysing the data as none of the existing research showed the analysis of tracing students' mechanistic reasoning across several topics. Nonetheless, there were two articles that shed light for the researcher which were Kinchin, Streatfield and Hay (2010) on using concept mapping to enhance the research interview and Attride-Stirling (2001) on using thematic network as a tool for qualitative research. Concept mapping is a product of research over the past 25 five years or so that has been spearheaded by Novak and his colleagues (Novak, 1998). Concept mapping has been widely used in research as a tool to support reflection (Fisher, 2000) or assessment tools (Van Zele, 2004) and to gauge cognitive structure (Hay, 2007; Kinchin, 2011; Kinchin, Hay & Adam, 2000; Van Zele, 2004). In recent years, concept mapping has becoming a tool used not to collect data directly but to reduce the data to structural summaries of knowledge and understanding (the way in which knowledge is structured and individual concepts connected to each other) (Kinchin, Streatfield and Hay, 2010; Van Zele, 2004). Attride- Stirling (2001) stated that a concept map (or she called it as thematic network) is a practical and effective procedure for conducting an analysis which enables the data to be more systematic, facilitates the organisation of the data and its presentation as well as allows a sensible, insightful and rich exploration of the data and underlying patterns. After reading those articles, the researcher began to employ a similar idea of concept mapping as a tool to present an overview of the chaining in students' mechanistic reasoning which is known as configuration in the present study.

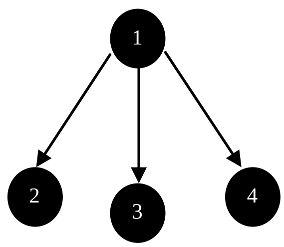
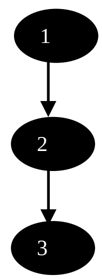
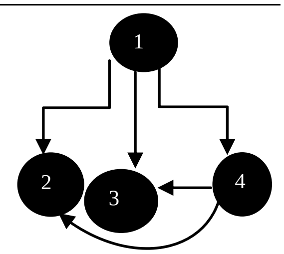
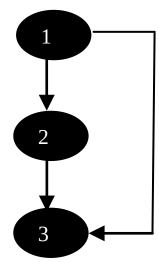
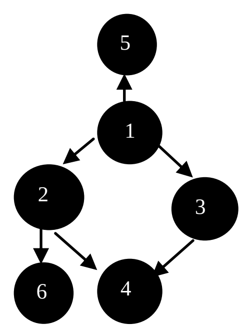
An example of a portion of the text converted into a configuration is shown in Example 1 in page 136. An overall example of configurations generated by H1 for the Theory of Cell is shown in Appendix M. The configurations generated by the high and low achieving students were verified by the same panel members.

Step 5: Exploring the types of configurations

Based on the configurations generated, the researcher scrutinised further to explore the similarities and differences that emerged from the configurations. The exploring of the configurations was aided by referring to the study conducted by Hay, Kinchin, and Lygo-Baker (2008). Finally, three different types of configurations were identified which are represented in Table 5.6. The data were peer reviewed by the same panel members and any discrepancies that arose were discussed until a consensus was reached.

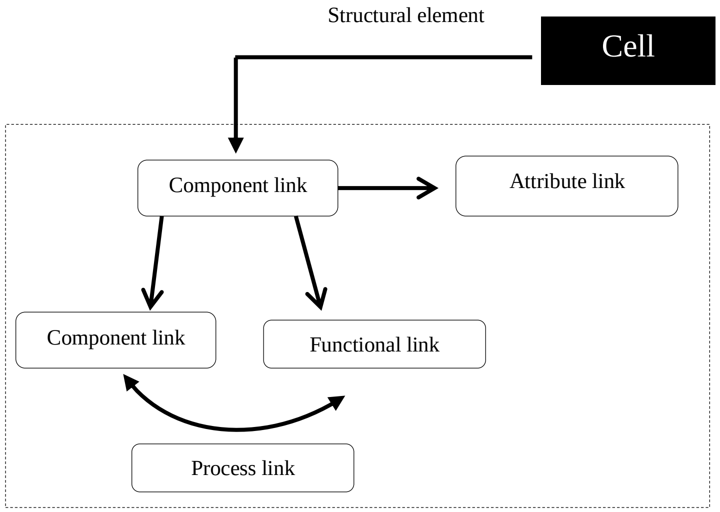
Table 5.6

Types of Configurations and their Related Characteristics

Types of configuration	**Spoke**	**Linear**	**Network**
			  
Hierarchy of configurations	Low	Low	High
Characteristics	Single link which are not connected among to each other. The links do not interfere with each other.	Single links in linear form. One link is connected to the other in a sequential manner.	Several cross links within a configurations Additional links within a spoke or linear configuration.

The following examples demonstrate the conversion of the types of the links into a configuration.

Example 1

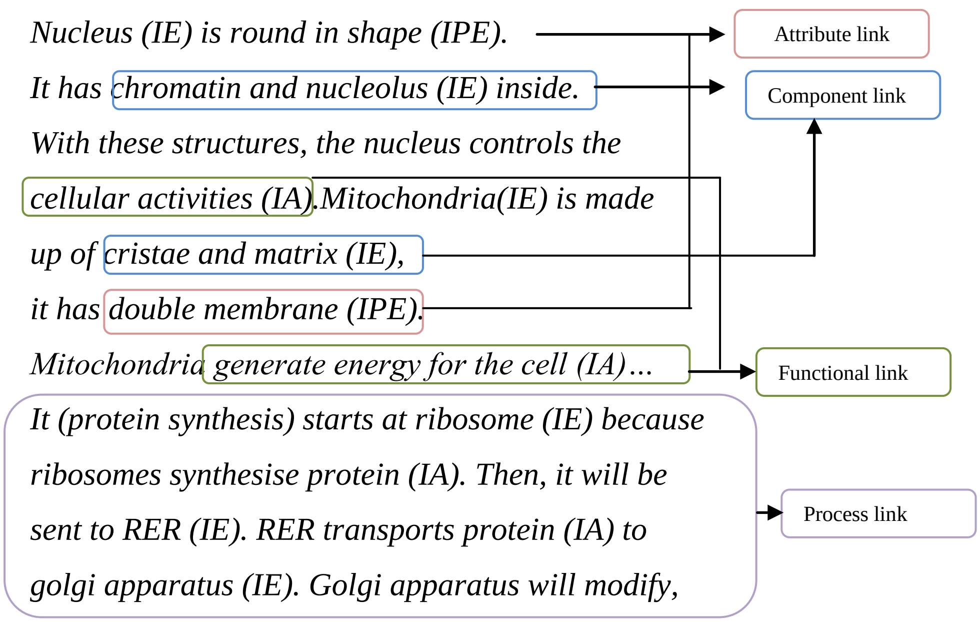
H1's written task	Configuration based on H1's written task
H1 : A nucleus (IE) is round in shape (IPE). It has chromatin and a nucleolus (IE) inside. With these structures, the nucleus controls the cellular activities (IA). Mitochondria(IE) is made up of cristae and matrix (IE), it has a double membrane (IPE). Mitochondria generate energy for the cell (IA)… It (protein synthesis) starts at the ribosome (IE) because ribosomes synthesise protein (IA). Then, it will be sent to RER (IE). RER transports the protein (IA) to the golgi apparatus (IE). The golgi apparatus will modify, package and transport (IA) it out of the cell in secretary vesicles (IE). Attribute link Component link Functional link Process link *(H1's written task Element: Structure, Topic: cell structure and organisation)*	

1, 2, 3, 4 – indicated the types of link involved
Types of link: component link, functional link, attribute link and process link.

The following discussion will describe the classification of the types of configurations based on the students' data.

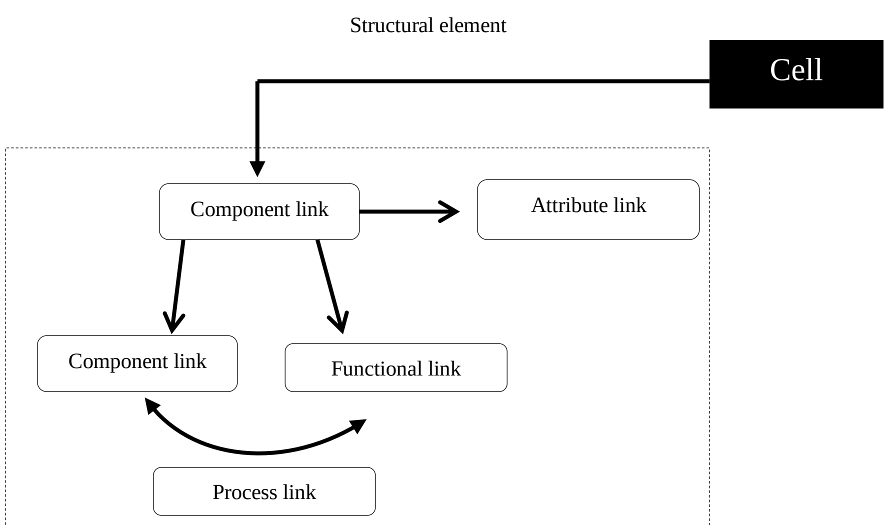
<u>Example 1</u>

H1 : *Nucleus (IE) is round in shape (IPE). It has chromatin and nucleolus (IE) inside. With these structures, the nucleus controls the cellular activities (IA).Mitochondria(IE) is made up of cristae and matrix (IE), it has double membrane (IPE). Mitochondria generate energy for the cell (IA)… It (protein synthesis) starts at ribosome (IE) because ribosomes synthesise protein (IA). Then, it will be sent to RER (IE). RER transports protein (IA) to golgi apparatus (IE). Golgi apparatus will modify, package and transport (IA) out of the cell in secretary vesicles (IE).*



(H1's written task
Element: Structure
Topic: cell structure and organisation)

H1's configuration for the structural element in phase I is:



Type of configuration: Network

Example 2

Attribute link

H3 : Skin (IE) is made up of skin tissues (IE) and skin tissues
are made up of skin cells (IE)...
Muscle cells require protein (IPE),
so they need a lot of RER (IA)...

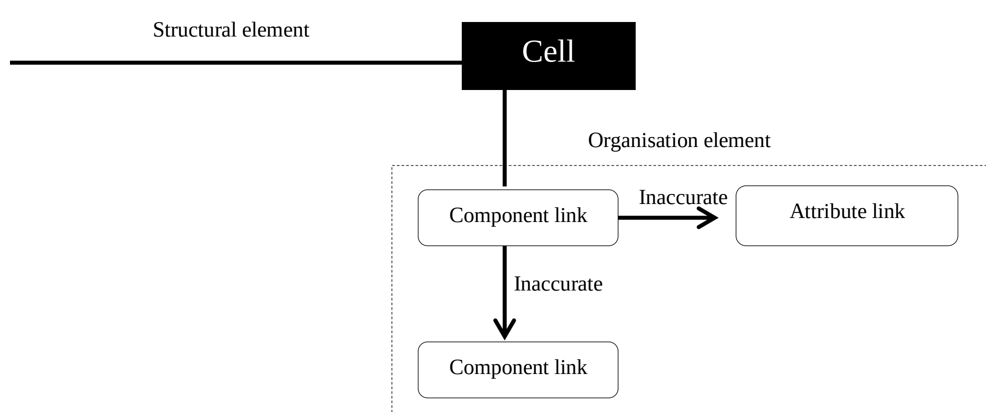
Component link

(H3's written task
Element: Organisation
Topic: cell structure and organisation)

R	*:*	*H3, can you explain the task?*
H3	*:*	*Sperm needs energy to swim to the ovum. Thus, mitochondria is needed to generate energy. Muscle cells require protein, so they need a lot of RER.*
R	*:*	*How do you know muscle cells require a lot of protein?*
H3	*:*	*Em…I don't know. I guess.*
R	*:*	*What about pancreatic cells and liver cells?*
H3	*:*	*Hm… I don't know the function of the cell, teacher.*
R	*:*	*What about metamorphosis of a tadpole?*
H3	*:*	*I don't know.*

(Excerpt from classroom discussion)

From the above written task by H3 as well as the excerpt from the classroom discussion, the configuration for the organisation element in phase I for H3 is:



Type of configuration: Spoke

Example 3

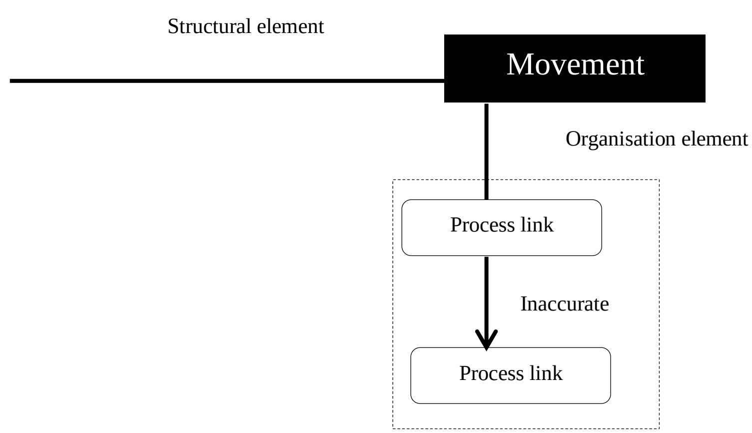
L2 : *Food is immersed into vinegar so that the food can be kept longer...* → Process link

(L's written task
Element: Organisation
Topic: movement of substances across the plasma membrane)

R : *Why the food is immersed into vinegar or salt solution?*
L2 : *So that it can keep longer.*
R : *How?*
L2 : *because vinegar can kill the bacteria.* → Process link

(Excerpt from classroom discussion)

From the above written task by L2 as well as the excerpt from the classroom discussion, the configuration for the organisation element in phase II for H3 is:



Type of configuration:

Step 6: Generating Chaining

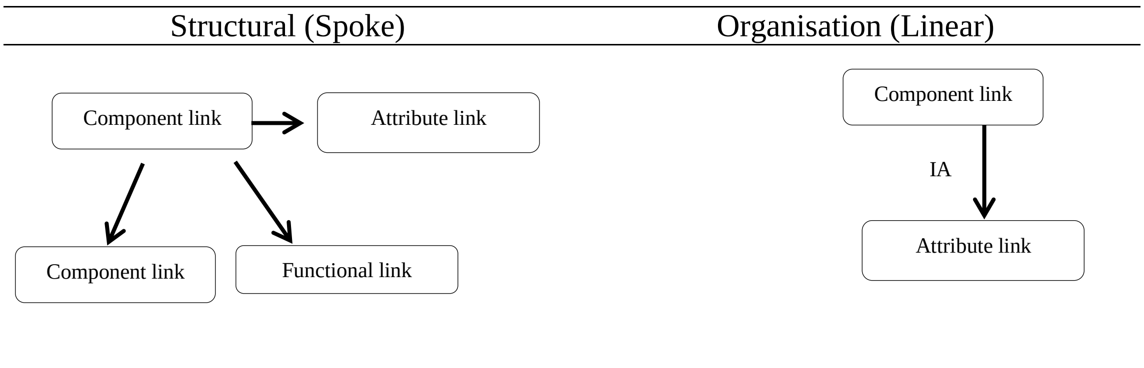
From the configurations constructed from each element (structural, organisation and genetics), students' data were scrutinised further to identity the chaining between the configurations across the elements within each phase and across the phases. For example, H1's mechanistic reasoning for the structural and organisation elements in phase I is shown in Table 5.7.

Table 5.7

H1's Mechanistic Reasoning for Structural and Organisation Elements in Phase I

Structural	Organisation
The plasma membrane controls the substances moving in and out (functional). ***Mitochondria*** *is made up of cristae and matrix(component), it has a double membrane(attribute).Ribosomes synthesise protein (functional).*	*The metamorphosis of a tadpole needs ribosome (inaccurate component link.) because the* ***tail is made up of protein*** *(inaccurate attribute link).Ribosomes synthesise protein.*

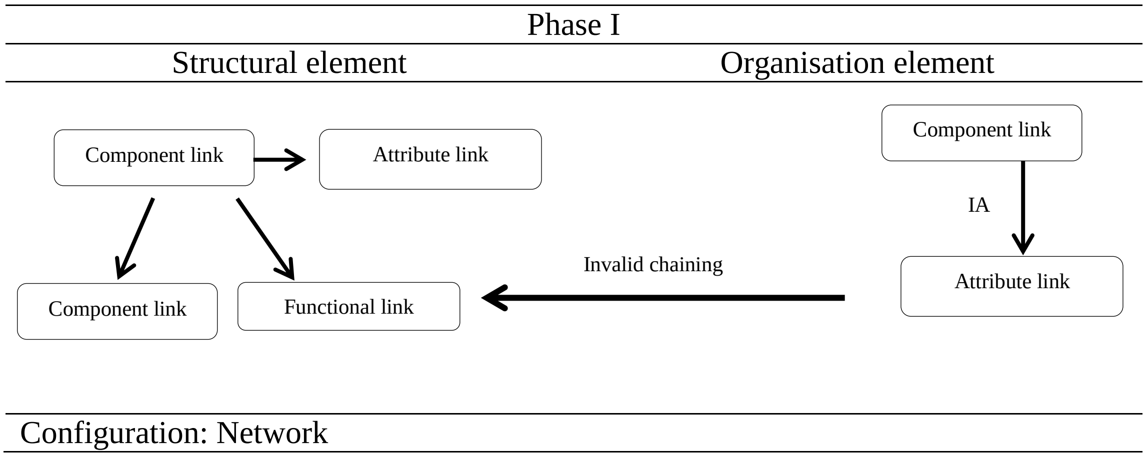
From H1's mechanistic reasoning in the structural and organisation elements, the configurations demonstrated by H1 in phase I is shown in Figure 5.3



IA – Inaccurate link

Figure 5.3. The configurations for structural and organisation elements in phase I

Based on H1's written answer in Figure 5.3, he chained his linear configuration (which consisted of an inaccurate attribute link - tails are made up of protein) in the organisation element (the metamorphosis of a tadpole) to the spoke configuration (which consisted of the component link - require ribosome; and the functional link - ribosome synthesises protein) in the structural element. Thus, the chaining between the structural and organisation elements is shown in Figure 5.4.



IA – Inaccurate link

Figure 5.4. The chaining between the configurations for the structural and organisation elements in phase I

Due to the inaccurate attribute link generated in the organisation element (tail of a tadpole is made up of protein), the chaining is invalid. However, H1 still showed his effort in constructing the connection to generate a network configuration.

Step 7: Interpreting Mechanistic Reasoning

After the links, configurations and chains had been established, the final step was to look more deeply at the cognitive processes that these links, configurations and chains between configurations imply. In the present study of mechanistic reasoning, the cognitive processes were categorised into simple and complex processing. Some criteria were developed to distinguish simple and complex cognitive processing. Simple and complex cognitive processing were further divided into level I and level II. The criteria to distinguish between simple and complex were based upon the theory postulated by Craik and Lockhart related to Type I and Type II levels of processing (1972). The criteria constructed were discussed and validated by the same panel members after much debate and discussion.

Simple cognitive processing in the present research context is defined based on Craik and Lockhart's Type I Level of processing (1972) whereby students are able to recognise patterns and elaborate but fail to perceive and construct meaningful semantic association in their reasoning. This is known as Type I processing.

The following criteria were used to identify Type I and Type II simple cognitive processing:

Type I Simple cognitive processing

The type I simple cognitive processing is characterised by:

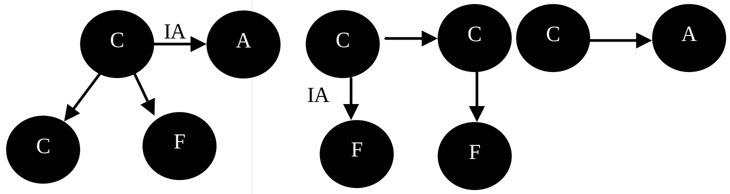
(a) Most of the links generated within a phase are inaccurate.

(b) Spoke and linear configurations within elements in a phase.

(c) Network configurations within elements in a phase.

(d) There is no chaining between the elements.

The following example will reveal the types of cognitive processing based on the links and chaining generated by the student.

Phase / Element	**Structure**	**Organisation**	**Genetics**	**Category**
Cell structure and organisation				Type I simple cognitive processing
Description	Inaccurate link in the structural element *A nucleus (component) controls the cellular activities (functional) . Mitochondria is round in shape, the golgi apparatus is curved in shape and the cell wall is located outside the cell (weak attribute).*			

C-Component F-Functional A-Attribute P-Process IA-Inaccurate link

Figure 5.5. An example of Type I simple cognitive processing

Figure 5.5 shows the type I simple cognitive processing in L1 for cell structure and cell organisation (phase I).

The configurations demonstrated by student L1 for phase I cell structure and organisation were spoke and linear. There was no chaining of the configurations between the elements within the phase and some of the links are inaccurate. Thus, L1's mechanistic reasoning in phase I can be categorised as type I simple cognitive processing.

Type II Simple cognitive processing

The type II simple cognitive processing is characterised by:

(a) Most of the links generated within a phase are accurate.

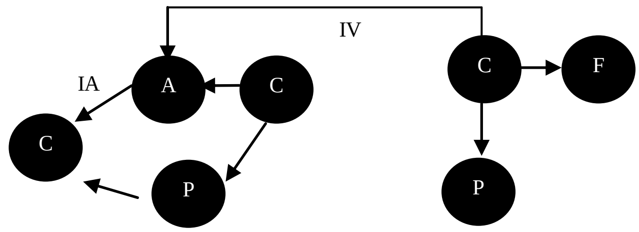
(b) Spoke and linear configurations within elements in a phase.

(c) Network configurations within elements in a phase.

(d) Network configurations between elements in a phase.

(e) The chaining between the configurations is invalid.

The following example in Figure 5.6 illustrates Type II simple cognitive processing for student L2 for Phase III (chemical composition of the cell).

Phase/Elements	**Structure**	**Organisation**	**Category**
Chemical composition of the cell			Type II simple cognitive processing
Description	<u>Inaccurate link in the structural element</u> *This is a saturated fatty acid because it has a single line (inaccurate attribute) while unsaturated fatty acid has a double line (inaccurate attribute).* <u>Invalid chaining between the structural and organisation elements</u> *Hair keratin, antibodies and enzymes are secondary structures (component) because they are coiled into α helix or β pleated sheet* (attribute). *Haemoglobin and growth hormone are quaternary (component) because they have more than two polypeptides (attribute).*		

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining

Figure 5.6. An example of Type II simple cognitive processing

As can be seen Figure 5.6, L2 most of the links generated within the phase are accurate. L2 constructed one network configuration across elements in the phase which indicates chaining within a phase. However, the chaining is invalid. Thus, L2's mechanistic reasoning in phase III can be categorised as type II simple cognitive processing.

The following criteria were used to identify type I and type II complex cognitive processing:

Type I Complex cognitive processing

The type I complex cognitive processing is characterised by:

(a) Most of the links generated within a phase are accurate.

(b) No Spoke and linear configurations within elements in a phase.

(c) Network configurations within elements in a phase.

(d) Network configurations between elements in a phase.

(e) There is chaining between configurations between elements within a phase

(f) There is chaining between configurations across phases.

(g) The chaining between configurations is invalid.

Figure 5.7 shows Type l complex cognitive processing for L4 for the movement of substances across the plasma membrane (phase II).

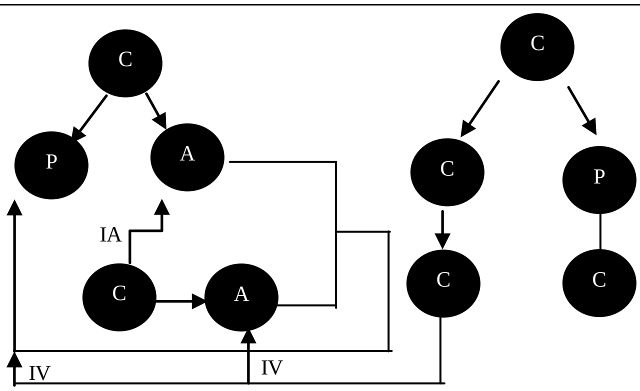
Element	**Structure**	**Organisation**	**Category**
Movement of substance across the plasma membrane			Type I complex cognitive processing
Description	<u>Invalid chaining between the structural and organisation elements</u> *The food is immersed into vinegar or salt solution so that the food won't rot (process). This is because vinegar can kill bacteria (process).*		

Figure 5.7. An example of Type I complex cognitive processing

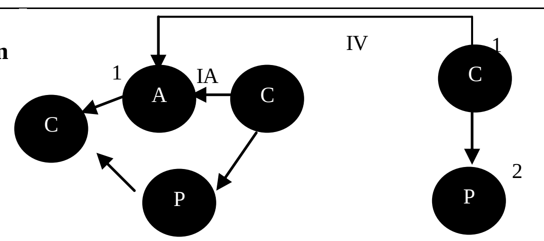
	Chemical composition of the cell (phase III) *L1 : A nucleus has a nuclear membrane and a DNA (Additional link as compared to phase I, Chain to phase I). The membrane is made up of phospholipids and transport protein (Chain to phase II). So, the organic components are lipids and protein (Chain to phase III)*

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining

Figure 5.7. (Continued)

There are no spoke and linear configurations between the elements within a phase in L4's configuration. There are network configurations within an element as well as across elements in a phase which indicates chaining between the elements within a phase. The links generated within a phase are accurate. However, the chaining in the configurations is invalid. Thus, L4's mechanistic reasoning in phase II can be categorised as type I complex cognitive processing.

Figure 5.8 shows another example of Type I simple cognitive processing demonstrated by L1 for chemical composition of the cell (phase III).

Element	**Structure**	**Organisation**	**Category**
Chemical composition of the cell			Type I complex cognitive processing
Description	Cell structure and organisation (phase I) *L1 : Nucleus consists of nuclear membrane. Mitochondria…*		

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
1, 2, 3- Indication of the chaining across phases

Figure 5.8. An example of Type I complex cognitive processing

There are no spoke and linear configurations between the elements within a phase in L1's configuration. He generated a network configuration within a phase and two network configurations across phases which indicate chaining between phase II and phase III. The links generated within a phase are accurate. However, the chaining in the configurations is invalid. Thus, L1's mechanistic reasoning in phase III can be categorised as type I complex cognitive processing.

Type II Complex cognitive processing

The type II complex cognitive processing is characterised by:

(a) Most of the links generated within a phase are accurate.

(b) No Spoke and linear configurations within elements in a phase

(c) Network configurations within elements in a phase

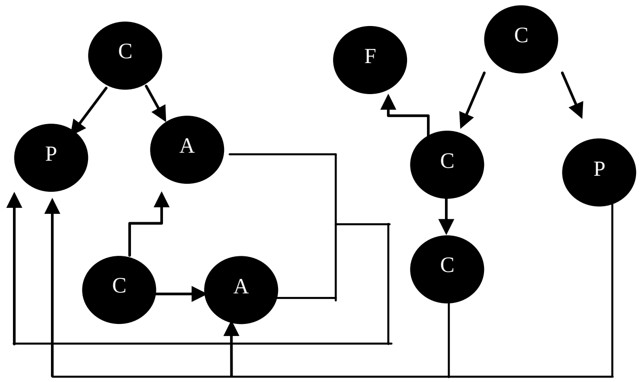
(d) Network configurations between elements in a phase.

(e) There is chaining between configurations between elements within a phase

(f) There is chaining between configurations across phases

(h) Most of the chaining between configurations is valid.

Figure 5.9 shows Type II complex cognitive processing demonstrated by H2 for the movement of substances across the plasma membrane (phase II).

	Structure	Organisation	Category
Movement of substance across the plasma membrane			Type II complex cognitive processing
Description	valid chaining between the structural and organisation elements *Too much of fertiliser causes less water concentration in the soil and high water concentration in root hair cells (attribute). The soil is hypertonic compared to the plant (attribute). Water moves out from the plant by osmosis (process). The plant wilts (process).*		

C-Component F-Functional A-Attribute P-Process

Figure 5.9. An example of Type II complex cognitive processing

There are no spoke and linear configurations between the elements within a phase in H1's reasoning. More than two network configurations within an element as well as in a phase were demonstrated which indicates chaining between the elements within a phase. The links generated within a phase are accurate and the chaining in the configurations is valid. Thus, H2's mechanistic reasoning in phase II can be categorised as type II complex cognitive processing.

After categorising all the mechanistic reasoning for high and low achieving students, the data can then be illustrated in the form of a line graph to give an overview of their cognitive processing. For example, the overall cognitive processing for H1 is shown in the Table 5.8.

Table 5.8

Overall Cognitive Processing for H1

Phase	**Topic**	**Types of cognitive processing**
Phase I	Cell structure and organisation	Type II simple cognitive processing
Phase II	Movement of substances across the plasma membrane	Type I complex cognitive processing
Phase III	Chemical composition of the cell	Type I complex cognitive processing
Phase IV	Cell division	Type I complex cognitive processing

Based on the configurations, H1's mechanistic reasoning in phase I – cell structure and organisation is type II simple cognitive processing. Due to more network configurations for movement of substances across the plasma membrane (phase II) were constructed, his mechanistic reasoning was categorised as type I complex cognitive processing. However, his reasoning was sustained at type I complex cognitive processing for the next two phases. Figure 5.10 shows the overview of H1's mechanistic reasoning for the four topics.

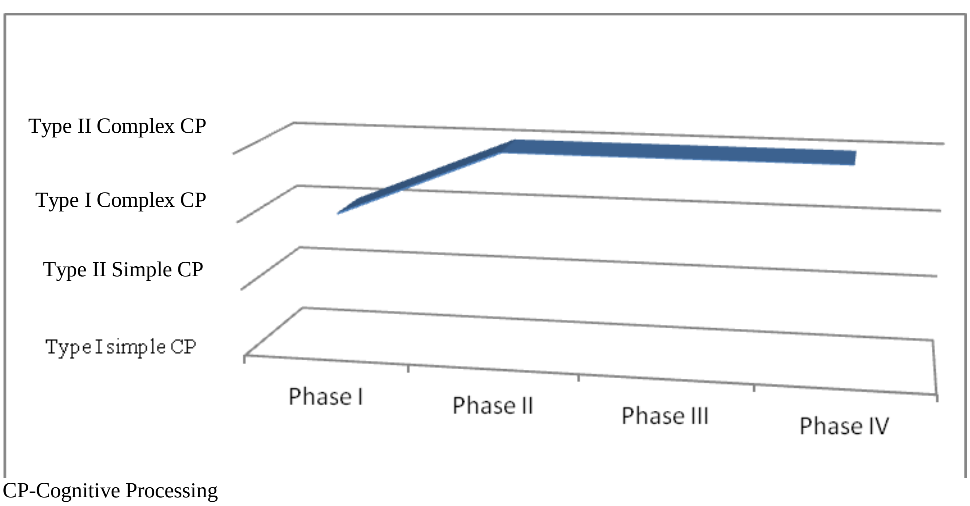


Figure 5.10. H1's overall change of cognitive processing over time

The line graph indicates H1 has failed to achieve type II complex cognitive processing. Probably due the failure of constructing more accurate chaining has impeded H1 to proceed to type II complex cognitive processing although his reasoning indicated that he was making effort to chain the configurations.

Summary of Students' Mechanistic reasoning

The analysis of students' mechanistic reasoning was a complex process as data collected over five months was overwhelming. The data was firstly organised before the analysis process begin. Once the data had been orderly arranged, students' mechanistic reasoning was dissected according to the principles for the Theory of Cell to different elements (structure, function and genetics) in each phase. This is followed by coding the material using Russ et al. (2008) analytical framework. After the coding process, different types of links were identified and the links were converted into configurations. Based on the configurations, the researcher further explored the types of configurations emerged. Students' mechanistic reasoning, now, was scrutinised further to generate the chaining within a phase or across the phases. Finally, based on the links, configurations and chaining, the researcher interpreted students' mechanistic reasoning based on four types of cognitive processing which are type I and II simple cognitive processing as well as type I and type II complex cognitive processing.

Based on Craik and Lockhart (1972) Levels of Processing, the preliminary stage is concerned with matching and assimilating the input with past learning. This is important to proceed to deeper cognitive processing. If matching is successful, students might be able to extend their reasoning. If matching or assimilating is unsuccessful, the extension might be inaccurate or students were unable to further elaborate or extend their mechanistic reasoning. This processing is known as Type I processing which is equivalent to simple cognitive processing in the present study.

The type II processing takes place at deeper levels where the subjects can make greater use of past knowledge and construct higher sematic association. In the present study, it refers to the chaining constructed in students' reasoning within a phase and across phases. The more valid chaining the students constructed, the more complex their cognitive processing are. Therefore, they were able to proceed to complex cognitive processing.

Figure 5.11 shows the overall analysis process of students' mechanistic reasoning.

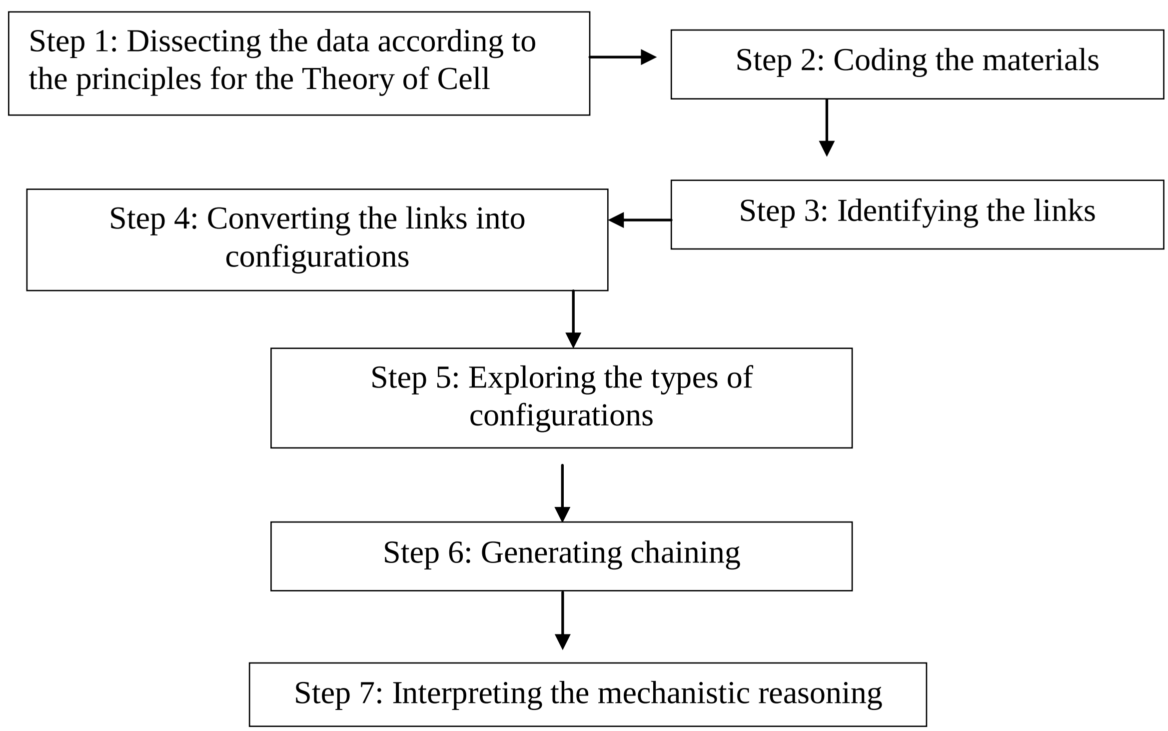


Figure 5.11. Overall steps in analysing students' mechanistic reasoning

Analysis of Students' Representations for the Theory of Cell

After the analysis of students' mechanistic reasoning, students' data were scrutinised further. Students' overall mechanistic reasoning revealed several representations.

The representations can be considered as the outcomes of mechanistic reasoning. These representations appeared to be of increasing complexity. How these representations were analysed will now be discussed.

Representations Categorised as the *Intuitive Representations*

In depth scrutinizing of students' data, it was found that in several occasions, in their mechanistic reasoning appeared to merely base their reasoning on intuition. Therefore, these reasoning are labelled as intuitive representation. An example is shown in Table 5.9.

Table 5.9

An Example of Intuitive Representations Showed by H2

H2, Phase I, Genetics element
Muscle cells and liver cells have different genetics information because everything cannot be the same.

Based on Table 5.9, the underlined section indicated the student was much based on his intuition or assumption instead of reasoning mechanically. The reasoning also indicated a non-scientific idea.

Representations Categorised as *Assimilated Representations*

As the students learnt through the phases, their mechanistic reasoning showed that they had assimilated the content step by step, matching each piece of new knowledge with the one learnt earlier. This is labelled as assimilated representations. An example is shown in Table 5.10.

Table 5.10

An Example of Simple Assimilated Representations Showed by L6

H4, Phase I, Organisation element
In metamorphosis of a tadpole, the tail will be replaced (process). Pancreatic cells produce enzyme (functional).

It emerged from the data that L6 was able to match his previous knowledge which he had learnt in science at the lower secondary level such as pancreatic cells produce enzymes. However, no further elaboration for pancreatic cell and the metamorphosis of tadpole has been constructed. Therefore, this is labelled as simple assimilated representation.

Some students' mechanistic reasoning revealed that they were able to assimilate with previous learnt knowledge from what have learnt earlier during science classes at the lower secondary as well as from phase to phase. Thus, their mechanistic reasoning revealed elaboration of their assimilated information. An example is shown in Table 5.11.

Table 5.11

An Example of Elaborated Assimilated Representations Showed by L3

L3, Phase II, Organisation element
The soil become less water when more fertiliser is added (attribute).Water moves out from the plant by osmosis (process) because plant has more water concentration (attribute). Finally, the plant wilts (process).
↓ Assimilate the process ↓ Elaboration of the assimilated information

It emerged from the data that L3 not only able to assimilate the consequence of excess fertilisers in a plant to osmosis concept (in structural element), but also manage to extend his reasoning by explaining how the process takes place based on the different concentration. Therefore, the research categorised this as elaborated assimilated representations.

In some students' mechanistic reasoning, assimilation and elaboration also occurred across phases whereby they were able to match with their previous learnt knowledge across phases to extend their reasoning. An example is shown in Table 5.12.

Table 5.12

An Example of Elaborated Assimilated Representations across Phases Showed by L1

L1, Phase I, Structural element
Nucleus has nuclear membrane (component). Cell wall is rigid (attribute). Vacuole has store water (functional). Chloroplast carries out photosynthesis (functional). Golgi apparatus transport protein, lipids and carbohydrate.
L1, Phase III, Organisation element
Nucleus has nuclear membrane and DNA. Membrane is made up of phospholipids and transport protein. So, the organic component is lipids and protein. Cell wall is rigid so it is made up of carbohydrate, protein and lipid. Chloroplast has made up of starch because it carries out photosynthesis.
→ Assimilation and Elaboration

Based on Table 5.12, in phase I, L1 stated the nucleus has nuclear membrane. In phase III, he was able to extend this idea to nucleus has membrane and DNA. In addition, he was able to elaborate the nuclear membrane is made up of phospholipid bilayer which he had learnt in phase II. Finally, he also elaborated that the organic components that made up of nucleus were lipids and protein which he learned in structural element in phase III. Therefore, the research categorised this as elaborated assimilated representations across phases.

Representations Categorised as *Transformational representations*

Some students' mechanistic reasoning showed replacing of previous old learning knowledge with a more accurate one after learning a new concept or prompting. An example is shown in Table 5.13.

Table 5.13

An Example of Transformational Representations Showed by H1

H1, Phase I, Organisation element

R : You wrote heart is made up of muscles tissues, why?
H1 : Because they need muscle to pump blood.
R : <u>Is heart only made up of muscle tissues</u>?
H1 : <u>Yes. Muscle tissues are built from muscles cells</u>.
R : No other tissues?
H1 : I don't think so. Pump blood requires muscle tissues.

(H1, Excerpt from interview, Task 3 Phase I)

H1, Phase II, Organisation element

Small intestine is made up of <u>muscle cells (component) because of peristalsis (process)</u>. Then, it is also made up of <u>blood cells (component) because it consists of blood capillaries (attribute)</u>. <u>Blood capillaries also made up epithelial cells (component).</u>

(H1's written task 6, Phase II)

↓ Transformation

Based on Table 5.13, in phase I, student H1 assumed that heart is only made up of muscle tissues and muscle tissues are built from muscle cells. However, his mechanistic reasoning indicated transformation of an organ is actually made up of multiple types of cells in phase II. This transformation has enabled him to elaborate his mechanistic reasoning, for example, he was able to state the function of muscle cells in small intestine is due to peristalsis. Therefore, the researcher categorised this as <u>transformational representations.</u>

Representations Categorised as *Misinterpreted Representations*

Students might able to construct representations such as transformation or elaborated assimilated representations; nonetheless, the representations might not be accurate all the time. Students might incorrectly interpret the knowledge they had learnt which is revealed in their reasoning. An example is shown in Table 5.14.

Table 5.14

An Example of Misinterpreted Representations Showed by L6

L6, Phase IV, Organisation element
Non-disjunction occurs because the spindle fibre is imbalanced and no crossing over. (inaccurate process link)

It emerged from the data that although L6 was able to assimilate “spindle fibre imbalance” and “no crossing over” in his mechanistic reasoning which he had learnt in meiosis, however, his reasoning indicated incorrect interpretation of the knowledge. This is because non-disjunction is not caused by spindle fibre imbalance or no crossing over. This revealed that the mechanisms put forward by L6 were not well comprehended and lead to incorrect assimilation. Incorrect assimilation might also lead to incorrect elaboration of their mechanistic reasoning. Therefore, the research categorised this as misinterpreted representations.

Summary

This chapter showed the steps that were taken to analyse students’ mechanistic reasoning in this study. Analysing students’ mechanistic reasoning was a robust process which involved the exploration of the links generated, the chaining as well as the configurations constructed. Based on these characteristics, students' mechanistic reasoning was classified into different types of cognitive processes mainly Type I and II simple cognitive processing as well as Type I and II complex mechanistic reasoning.

Students' overall mechanistic reasoning was scrutinised further to identify the outcomes of their mechanistic reasoning. There are four representations emerged from the data which are intuitive, assimilated, transformational and misinterpreted representations

Based on the analysis, students' mechanistic reasoning findings and discussion is reported in the next chapter.