CHAPTER 6

FINDINGS AND DISCUSSION

Introduction

This study set out to explore Form Four Science high achieving and low achieving students' mechanistic reasoning over time. The mechanistic reasoning generated in this study was generated by each individual high achieving and low achieving science student within 5 months of teaching and learning the Theory of Cell. 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 through chaining (Cummin, 1975, Craver, 2001, Darden & Craver, 2002, Russ et al., 2008). The study further elaborated this chaining into configurations and finally into levels of cognitive processing. Some promptings were given to assist the students to clarify and understand their reasoning. It was a difficult task to explicitly describe the students' mechanistic reasoning due to the nature of its subjectivity. However, useful findings were obtained and will be discussed in this chapter.

Firstly, low achieving and high achieving students' mechanistic reasoning for The Theory of Cell that emerged over five months of lessons using the Living Cell Tool is presented and discussed. Then, students' mechanistic reasoning progression over time is reported and finally students' mechanistic reasoning outcomes are discussed. An outline of the three parts is given below:

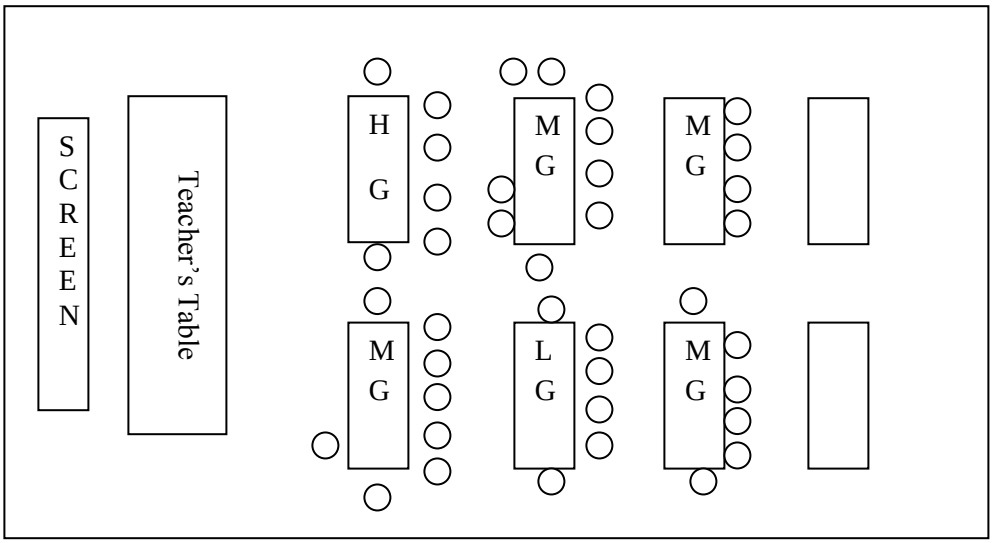
Part 1: Students' Mechanistic Reasoning

Part 2: Students' Mechanistic Reasoning Progression

Part 3: Students' Mechanistic Reasoning Representations

Students' Mechanistic Reasoning

Before proceeding to the actual discussion on mechanistic reasoning, the researcher would like to describe the classroom management. Firstly, since students were categorized into high and low achieving students, the seating had to be arranged carefully. Figure 6.1 shows the students' seating arrangement throughout the research period. There are four high achieving students and eight low achieving students obtained from the results of the Science Test distributed before the lesson commenced. However, due to the low attendance rate of two of the low performing students, only 6 low achieving students' data was taken into account.



HG – High achieving group MG – Medium achieving group LG – Low achieving group
◯ 1 represent one student's seating

Figure 6.1. Students seating arrangement in the laboratory

The mechanistic reasoning among 4 high and 6 low achieving students for the Theory of Cell will be reported in the first section. This will be followed by the comparison of mechanistic reasoning between high and low achieving students and eventually the patterns of mechanistic reasoning among high and low achieving students will be

documented. The findings were constructed through the analysis of information gathered from the students' written tasks in the Living Cell Tool , semi-structured interviews and classroom observations.

High achieving students are represented by H1, H2, H3 and H4 while low achieving students are represented by L1, L2, L3, L4, L5 and L6. Students' demographic data for the high and low achieving students is shown in Table 6.1.

Table 6.1

High and Low Achieving Students Demographic Data

Student	Gender	Age
H1	M	16
H2	M	16
H3	F	16
H4	M	16
L1	M	16
L2	F	16
L3	M	16
L4	M	16
L5	F	16
L6	M	16

In the discussion, the term 'phase' is used to refer to the sequence of the topics taught from January to May which was aligned with the curriculum specification of Biology. Each phase comprised of three elements (except for phases II and phase III which only had 2 elements) which were referred to as cell structure, cell organisation and genetics. Table 6.2 indicates the phase and elements in the research context.

Table 6.2

The Phases and Elements in the Research Context

Phase	Element	Topic
I	Structure	Cell structure and organisation
	Organisation	
	Genetics	
II	Structure	Movement of substances across the plasma membrane
	Organisation	
III	Structure	Chemical composition of the cells.
	Organisation	
IV	Structure	Cell division
	Organisation	
	Genetics	

High and Low Achieving Students' Mechanistic Reasoning

The discussion in this section describes the mechanistic reasoning for each of the high and low achieving students'. The first student to be referred as H1.

Table 6.3

H1's Overall Mechanistic Reasoning for the Theory of Cell.

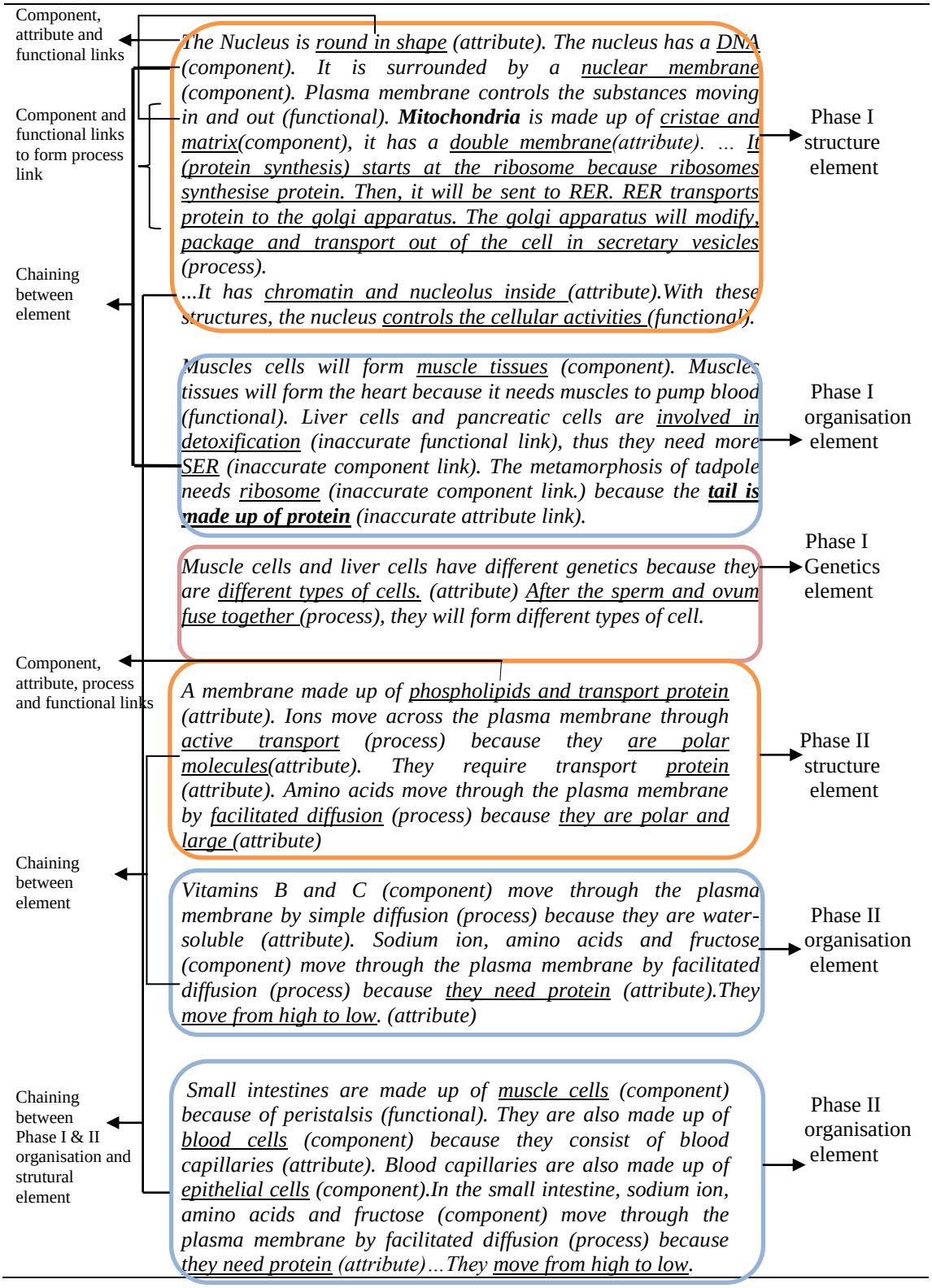


Table 6.3 (Continued)

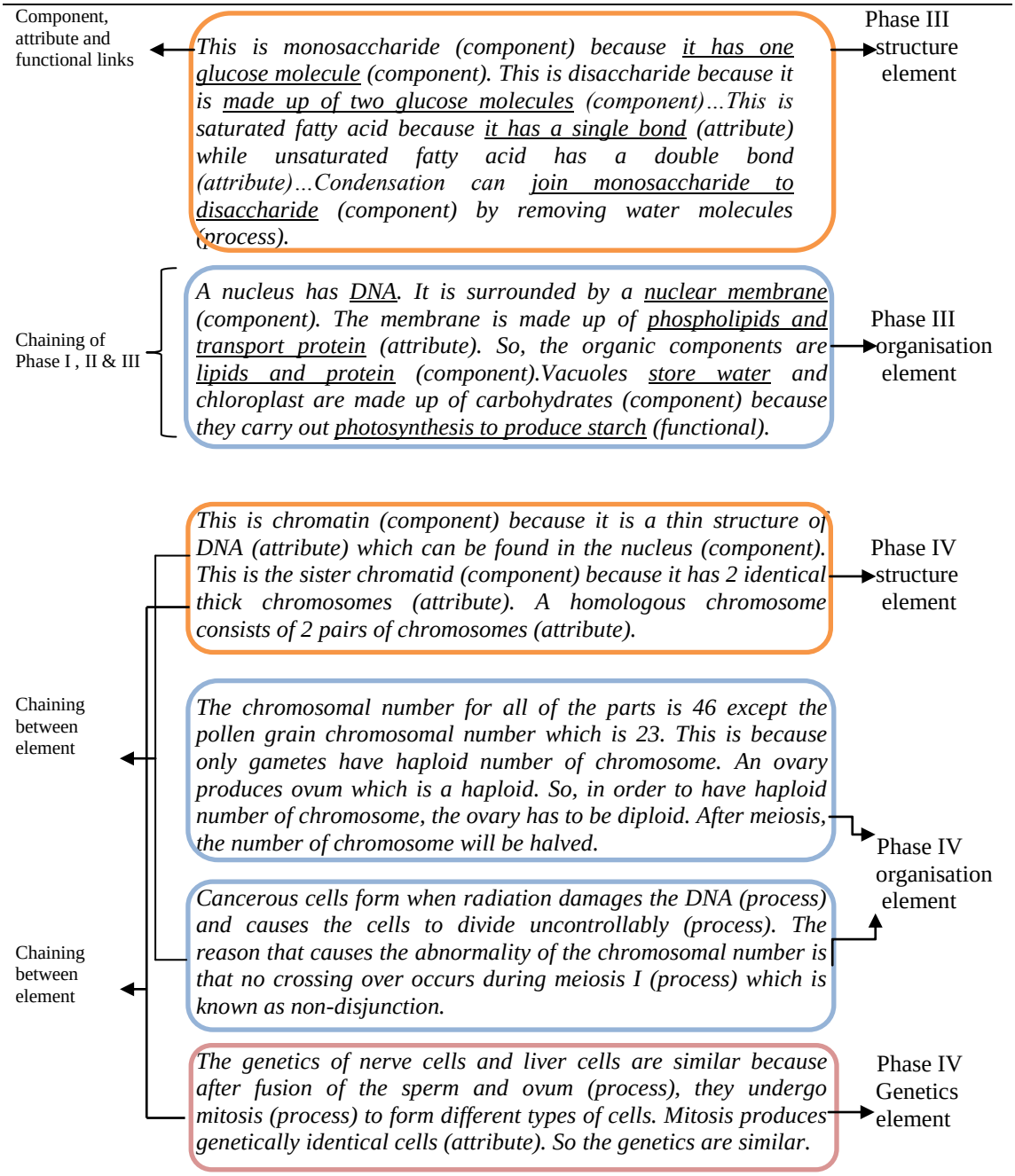


Table 6.3 shows H1's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by H1 comprises the component, attribute, functional and process links for the Theory of Cell in all the phases as

shown in Table 6.3. The process in which H1 has also managed to chain these links between the elements within a phase as well as across phases as is indicated in the table.

The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I, H1 demonstrated Type II simple cognitive processing and in phases II to IV, H1 demonstrated Type I complex cognitive processing. These types of processing will now be discussed.

Type II Simple Cognitive Processing

In phase I (Figure 6.3), the component, attributes and functional links formed within each element were classified as having spoke and network configurations. The majority of the links are accurate. A network configuration was formed between structural and organisation elements. The only chain that formed the network configuration was invalid. Thus, H1's reasoning was classified as Type II simple cognitive processing in phase I.

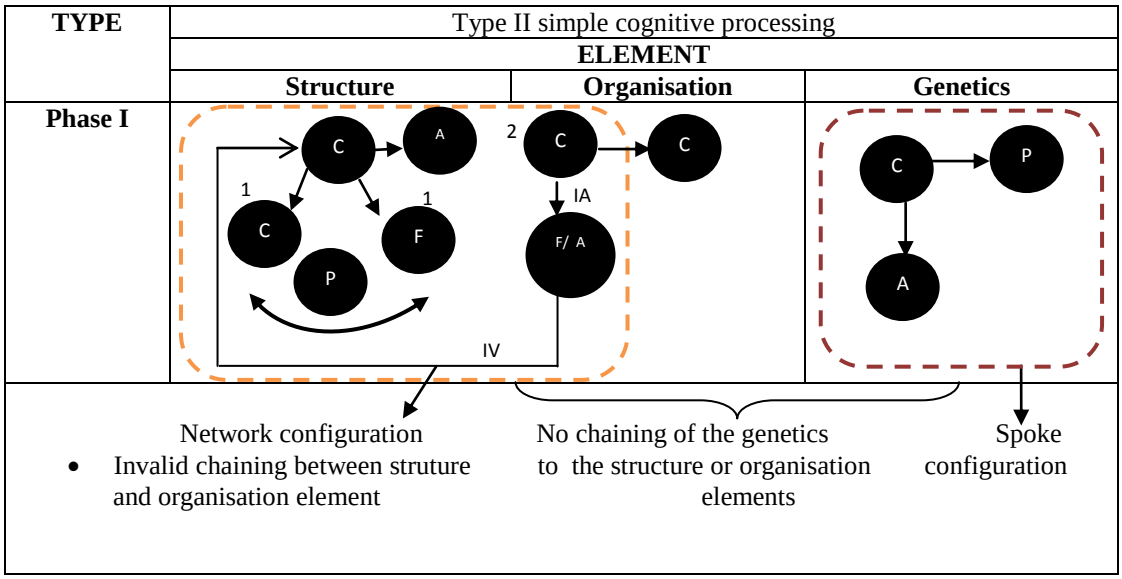


Figure 6.2. H1's Type II simple cognitive processing in phase I

Description for invalid chaining in a network configuration between organisation and structural element

Liver cells and pancreatic cells are involved in detoxification (inaccurate functional link), thus they need more SER (inaccurate component link). The metamorphosis of tadpole needs ribosome (inaccurate component link.) because its tail is made up of protein (inaccurate attribute link).

Description for spoke configuration within genetics

Muscle cells and liver cells have different genetics because they are different types of cells (attribute link). After the sperm and ovum fuse together, they will form different kinds of cell.(process link)

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase I, II and III (discussed in phase III Type I complex cognitive processing)
Indicated as 2 – Chaining to phase II (discussed in phase II Type I complex cognitive processing)

Figure 6.2. Continued

Based on Figure 6.2, most of the links within each element were accurate. However, the functional and attribute links in the organisation element were inaccurate. For example, H1 identified the function of pancreatic cells as detoxification (an inaccurate functional link). H1 also stated that the tail of a tadpole is made up of protein which is an inaccurate attribute link.

In phase I, H1 attempted to chain between the organisation and the structural elements and managed to create a network configuration. However, the chain generated was invalid due to the inaccurate attribute and functional links in the organisation element.

As for the genetics element, H1 generated a spoke configuration for attribute links but failed to chain it to the structural and organisation element.

Hence in phase I, H1 for most of the time managed to generate accurate links although there were few inaccurate ones. In addition, chaining between the elements was

attempted by H1, and a network configuration was formed; yet, the chaining was invalid. Therefore in phase I it can be said that H1 was at Type II simple cognitive processing.

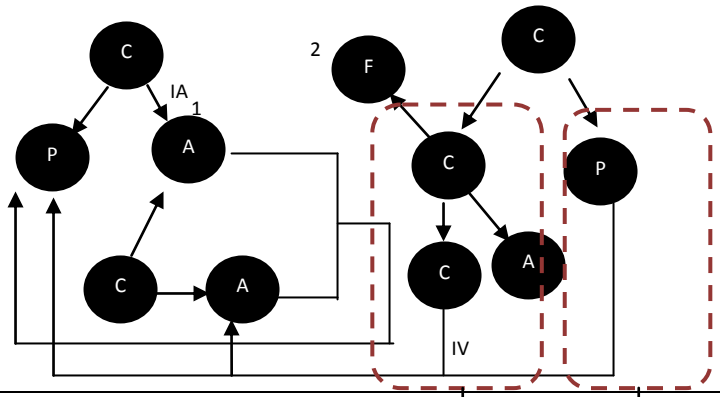
Type I Complex Cognitive Processing

Between phases II to IV, H1 demonstrated more accurate links and attempted more instances of chaining between elements within a phase to form several network configurations. However, several links and chains were inaccurate. In phase II, H1 revealed contradictions in the links generated. This will be discussed in more detail.

In Figure 6.3, there are no spoke or linear configurations formed in phase II. All the elements which were chained formed network configurations. However, a few of the links were inaccurate and also showed contradictions. For example, in Figure 6.3, H1 was able to construct accurate linkages between the process and the attribute links (for example, facilitated diffusion for big and polar molecules) within the structural element as shown in his written task 1. However, he constructed the attribute link differently for facilitated diffusion (requires protein and moves from a region of higher concentration to a region of lower concentration) in written task 6 which is within the organisation element.

Despite the contradiction, H1 was actually able to generate valid chaining for the process link in the organisation element to the structural element. For example, as described in Figure 6.3, H1 was able to chain the preservation process (process link in organisation element) to the osmosis concept (process link in structural element).

In phase II, H1 managed to generate accurate links. In addition, more chaining between the elements were attempted by H1 as several network configurations were formed; yet, the chaining was invalid. Therefore in phase II it can be said that H1 was at Type I complex cognitive processing.

TYPE	Type I complex cognitive processing	
	ELEMENT	
	Structure	**Organisation**
Phase II		

Description for invalid chaining between the organisation and structural elements

Ions move across the plasma membrane by active transport (process) because they are polar molecules (attribute). Amino acids move through the plasma membrane by facilitated diffusion (process) because they are polar and large (attribute). Written Task 1

Vitamin B and C (component) move through the plasma membrane by simple diffusion (process) because they are water-soluble (attribute). Vitamin A, D, E and K (component) are small (attribute) enough to pass through the plasma membrane by simple diffusion (process). Sodium ion, amino acids and fructose (component) move through the plasma membrane by facilitated diffusion (process) because they need protein (inaccurate attribute link in structural component). Written task 6

Valid chaining between the organisation and structural elements

Too much of fertiliser causes less water in the soil (attribute). The soil is hypertonic compared to the plant (attribute). Water moves out from the plant by osmosis (process). The plant dies (process).

Chaining across phases between organisation element in phase II and structural element in phase I

Small intestines are made up of muscle cells (component) because of peristalsis (process). Then, it is also made up of blood cells (component) because it consists of blood capillaries (attribute). Blood capillaries are also made up of epithelial cells (component).

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining across phase I, II and III (discussed in phase III Type I complex cognitive processing)
Indicated as 2 – Chaining to phase II (discussed in phase II Type I complex cognitive processing)

Figure 6.3. H1's Type I complex cognitive processing in phase II

In Figure 6.3, similar to phase II, there were no spoke or linear configurations formed in phase III. All the elements were chained to form network configurations. Despite the chaining within a phase, H1 also indicated chaining across the phases (which is indicated in blue 1). However, the chaining was invalid.

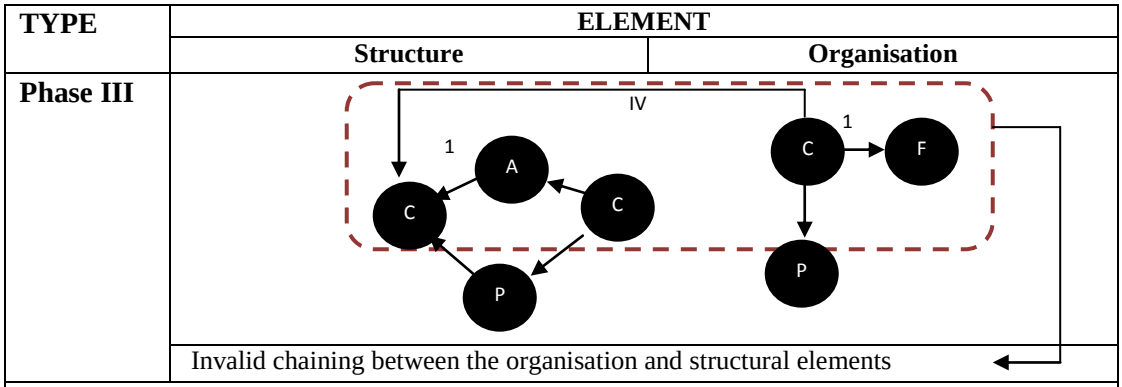


Figure 6.4. H1's Type I complex cognitive processing in phase III

The invalid chaining between structural and organisation elements revealed in phase III were due to the chaining of different types of links. For example, a component link was chained to its attribute link (nucleus is surrounded by a nuclear membrane, component link; the membrane is made up of phospholipids and transport protein, attribute link; the organic components involved are lipids and protein, component link) which gave rise to valid chaining. Nonetheless, some component links were chained to their function links instead

of attribute links (ribosome synthesize protein, functional link; thus they are made up of protein; component link); as such, this inaccuracy gave rise to invalid chaining.

In Figure 6.5, there are no spoke or linear configurations formed in phase IV. Most of the links generated within a phase are accurate. All three elements are chained to form network configurations. Although H1 made an effort to construct chains, the chaining was invalid.

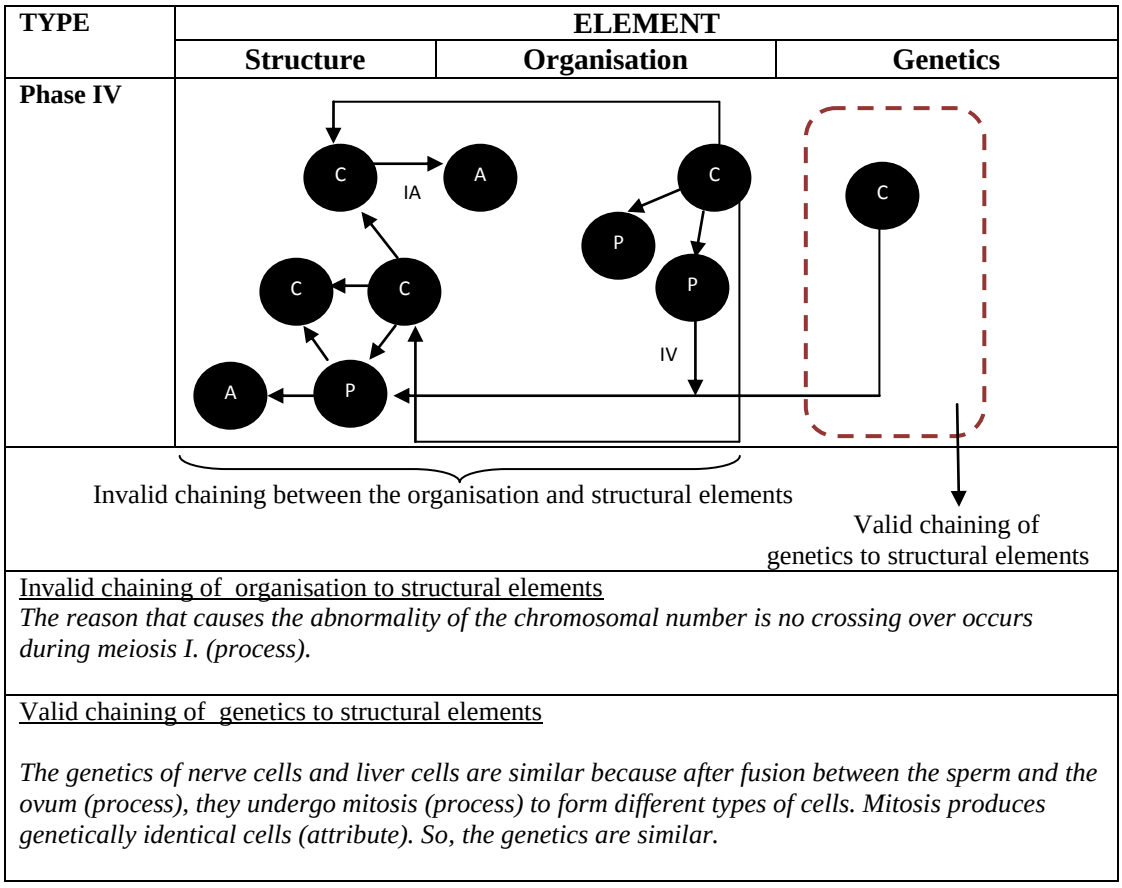


Figure 6.5. H1's Type I complex cognitive processing in phase IV

Based on Figure 6.5, many of the links within each element were accurate. However, most of the chaining was invalid especially between the structural and

organisation component. For example, in reasoning the causes of non-disjunction, H1 chained it to the crossing-over process (process link) in the structural element; however, no crossing over is not the main reason that contributed to the non-disjunction process. Therefore, the chaining is considered invalid. The only valid chaining constructed was between the genetics to the structural elements. Although H1 was able to chain the genetics to the structural elements in phase IV, however, how cells could develop into different types of cells remained unclear for H1. This was verified during an interview with H1 as shown below.

R : *You mentioned that mitosis produces genetically identical cells.*

H1 : *Yes.*
R : *Then, how are different types of cells produced?*
H1 : *(Silence). I am not sure. I guess because of nucleus.*
R : *Why?*
H1 : *Nucleus controls cell's activities.*

(H1, Excerpt from interview, Task 4 Phase IV)

The above excerpt revealed that H1 was able to chain forward (mitosis produces genetically identical cells in phase IV). Yet, he was unable to perceive the connection between the different types of cells formed from a process known as cell specialisation which was taught in phase I (chain backward). Based on H1's mechanistic reasoning, H1 might have compartmentalised the learning of cell specialisation in phase I where he failed to perceive the chaining between the generation of different types of cell with cell specialisation. Although the learning of genetics for a cell had been taught as he progressed to another phase, cell specialisation was still compartmentalised.

In phase IV, H1 managed to generate accurate links. In addition, more chaining between the elements were attempted by H1 as several network configurations were

formed; yet, the chaining was invalid. Therefore in phase IV it can be said that H1 was at Type I complex cognitive processing.

H1 did not achieve type II complex cognitive processing mainly due to a lack of valid chaining specifically between the organisation and structural elements which is shown in Figures 6.3, 6.4 and 6.5. Craik and Lockhart (1972) argued that a subject is able to proceed to type II processing if he/she could construct as many valid semantic associations as possible. In the present research context it refers to chaining. In order to construct valid sematic associations, the student is required to pick only relevant and accurate information which are the accurate links in the present research. Inaccurate or absence of links will only lead to invalid chaining which will impede the subject to move towards type II processing.

Table 6.4

H2's Mechanistic Reasoning for the Theory of Cell

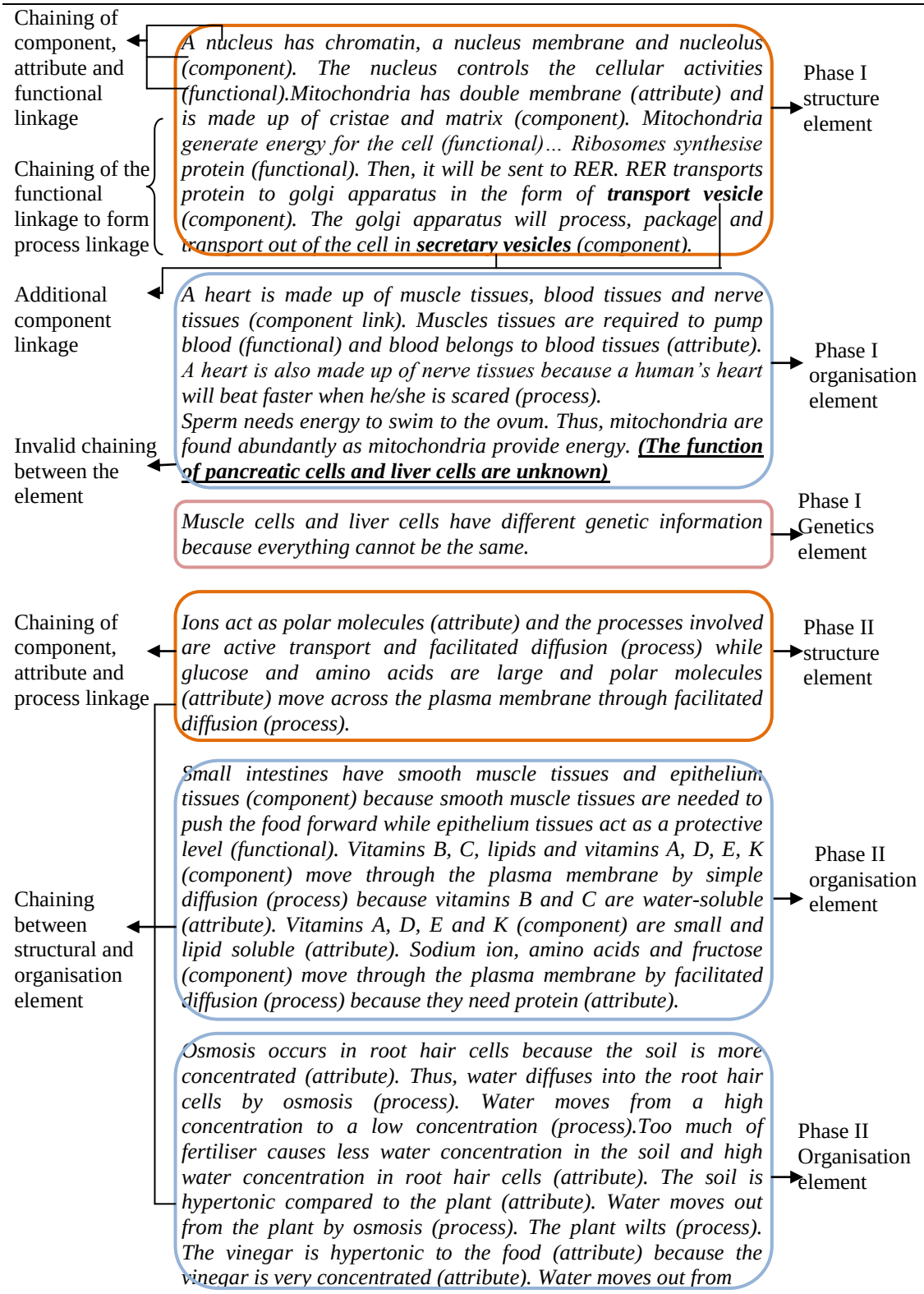


Table 6.4 (Continued)

the food by osmosis (process). The bacteria also becomes dehydrated (process) because of a lack of water (attribute).

*This is saturated fatty acid because it is a single bond (attribute) and is solid at room temperature (attribute) while unsaturated fatty acid has a double bond (attribute) which is liquified at room temperature (attribute)…**The process to join two monosaccharides (component) is condensation (process) which water molecules are removed (process). While hydrolysis (process) separate disaccharide to form two monosaccharides (component) by adding water.***

→ Phase III structure element

Chaining between structural and organisation element

*Hair keratin is a primary structure (component) because it is a linear polypeptide (attribute). Antibodies, enzymes and growth hormones are tertiary (component) because they have more than two polypeptides (attribute) and haemoglobin is quaternary (component) because it has more than three polypeptides (attribute). **Enzymes are required for hydrolysis and condensation processes because the process can be accelerated.***

→ Phase III organisation element

Chaining of phase I, II and III.

A nucleus (component) has a nuclear membrane (component). Membrane is made up of phospholipids and transport protein (attribute). So, the organic components are lipids and protein (component).Furthermore, membrane has cholesterol (component) which belongs to lipids (component) as well. Membrane also has glycolipids (component) which are made up of carbohydrate and lipids (component). Same as mitochondria (component) and golgi apparatus (component). Both have membrane (attribute) and the organic compounds which are involved are lipids and protein (component). A cell wall has cellulose (attribute). Cellulose is polysaccharide (component).

→ Phase III Organisation element

Chaining of phase I and phase IV structural element

*This is chromatin (component) because it is a double helix of **DNA** (attribute link) which can be found in the nucleus (component, phase I). This is the sister chromatid (component) because it is a chromosome in mitosis (attribute). And homologous chromosome (component) consists of 2 chromosomes in meiosis (attribute).*

→ Phase IV structure element

Chaining between structural and organisation element

The chromosomal number for all of the parts is 46, except for pollen grain, the chromosomal number is 23. This is because only gametes (component) have haploid numbers (attribute).The cells in an ovary has to be 46, so that after meiosis (process) the chromosomal number for gamete is 23 (attribute). The colour is brown because the nucleus in somatic cells (component) is used. The nucleus contains genetic information (attribute). Thus, the baby follows the cell with the nucleus (attribute). The reason that causes this (non-disjunction) is that the chromosomes fail to separate (process). Thus, it produces gametes (process) which have an abnormal number of chromosomes (attribute). Cancer cells are formed when mutation occurs (process) in the nucleus. Then, the cell starts to divide uncontrollably (process).

→ Phase IV organisation element

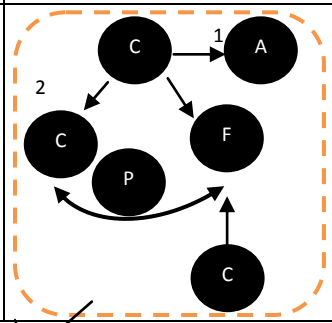
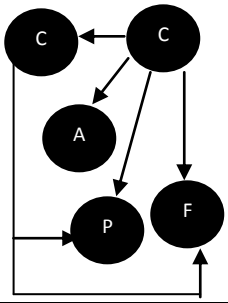
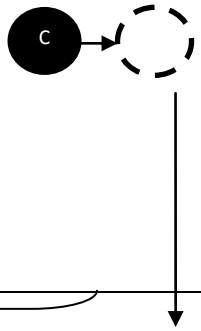
Table 6.4 (Continued)

Chaining between element ←	*The genetics of nerve cells and liver cells are similar because they are somatic cells which undergo mitosis (process). Mitosis produces genetically identical cells (attribute). So the genetics are similar. However, the genetics of sperm and an ovum are different because of crossing over (process).*	→ Phase IV genetics element

Table 6.4 shows H2's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by H2 comprises the component, attribute, functional and process links for the Theory of Cell in all the phases as shown in Table 6.4. How H2 has managed to chain these links between the elements within a phase as well as across phases is indicated in the table. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I, H2 demonstrated Type I simple cognitive processing and in phases II to IV, H2 demonstrated Type II complex cognitive processing. These will now be discussed.

Type I Simple Cognitive Processing

In phase I (Figure 6.4), the component, attribute and functional links formed within each element was classified as having spoke and network configurations. The majority of the links are accurate. Two network configurations were formed within the structural and organisation elements respectively. There was no chaining from the structural to genetics elements. Thus, H2's reasoning is classified as Type I simple cognitive processing in phase I.

TYPE	Type I Simple cognitive processing		
	ELEMENT		
	Structure	Organisation	Genetics
Phase I			
The network configurations	No chaining between the elements		No links generated

Description for network configuration in the structural element

A nucleus has chromatin, a nucleus membrane and a nucleolus (component). The nucleus controls the cellular activities (functional).Mitochondria has a double membrane (attribute) and is made up of cristae and matrix (component). Mitochondria generates energy for the cell (functional)… Ribosomes synthesise protein (functional). Then, it will be sent to RER. RER transports protein to the golgi apparatus in the form of transport vesicles (component link). The golgi apparatus will process, package and transport the protein out of the cell in secretary vesicles (component link).

Description for no chaining among the elements

i. ***Organisation element***

The function of pancreatic cells and liver cells were left blank by H2 in this answer.

ii. ***Genetics element***

Muscle cells and liver cells have different genetic information because everything cannot be the same. (No links generated)

Description for the additional links in the organisation element

*A heart is made up of muscle tissues, blood tissues and nerve tissues (component link). Muscle tissues are required to pump blood (functional ink) and blood belongs to blood tissues (attribute link). A heart is also made up of nerve tissues (component link) because a human's heart will beat faster when he/she is scared. (**additional process links**)*

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

Indicated as 1,2 – Chaining to phase III and IV (discussed in phase III Type I complex cognitive processing)

Figure 6.6. H2's Type I simple cognitive processing in phase I

Based on Figure 6.6, most of the links within each element were accurate in the structural and organisation elements. There were no related links generated for the genetics element as the reason for the different genetics information that he reasoned was 'everything cannot be the same'.

In phase I, H2 also showed no attempt in constructing chains between the structural, organisation and the genetics elements. However, H2 managed to generate network configurations within an element in phase I. For example, in the structural element, H2 was able to link the function and component in generating a process link.

The lack of chaining between the structural and organisation elements could be due to the absence of functional links for several types of cells specifically the pancreatic and liver cells. This can be supported in the following excerpt.

R : H2, can you explain the task.
H2 : Sperm needs energy to swim to the ovum. Thus, mitochondria is found abundantly as mitochondria provides energy….Pancreatic cell..em…
R : What about pancreatic and liver cells?
H2 : Hm… I don't know. Pancreatic cells are for digestion?

(H2, Excerpt from classroom discussion, Task 4 Phase I)

In the excerpt, H2 was unable to generate the functional link for liver and pancreatic cells, such as the liver cells are involved in detoxification. This had obstructed him from chaining to the correct organelles that could be found abundantly in the respective cells (structural element).

The lack of chaining in the genetics element mentioned above, was possibly also due to his inability to identify the related links when he was asked whether the cells shared similar genetic information. Consequently, there was no chaining between the genetics element to other elements. This is shown in the excerpt below.

R : *Do you think muscle cells and liver cells have the same genetic information?*
H2 : *No*
R : *Why?*
H2 : *I don't know. Everything cannot be the same right?*

(H2, Excerpt from classroom discussion, Task 3 Phase I)

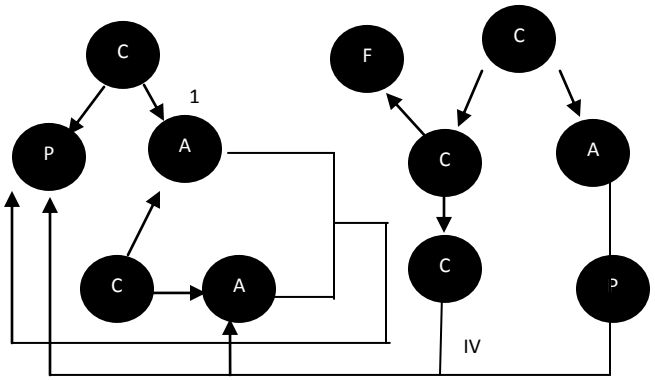
The failure in chaining the elements was mainly due to the inability to identify the types of links involved which had obstructed him to progress to type II simple processing (for example, the failure to identify the functional link in the organisation element or links in the genetics elements). The failure in identifying the types of link may have also caused the compartmentalisation of the elements which can be seen in Figure 6.6 as the elements are not chained to each other.

Hence in phase I, H2 for most of the time managed to generate accurate links. However, chaining the elements was not attempted by H2, and network configurations only formed within an element. Therefore, it can be said that H2 was at Type I simple cognitive processing in phase I.

Type II Complex Cognitive Processing

H2 demonstrated more accurate links between phases II to IV. He also began to chain in the following phases of II, III and IV and has more than 2 network configurations from the structure element to the genetics element and across the phases. In addition, the majority of the chaining was accurate which was categorised as type II complex cognitive processing.

Although H2 generated accurate links in phase II, there were links which contradicted each other for the movement of substances across the plasma membrane which is shown in Figure 6.7.

Phase	Type II Complex cognitive processing	
	ELEMENT	
	Structure	Organisation
II		

Valid chaining between the organisation and structural elements

Description for chaining between the organisation and structural elements

Vitamins B, C, lipids and vitamins A, D, E, K (component) move through the plasma membrane by simple diffusion (process) because vitamins B and C are water-soluble (attribute). Vitamins A, D, E and K (component) are small and lipid soluble (attribute). Sodium ion, amino acids and fructose (component) move through the plasma membrane by facilitated diffusion (process) because they need protein (attribute).

Too much of fertilizer causes less water concentration in the soil (attribute) and high water concentration in root hair cells .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 IA- Inaccurate link
IV-Invalid chaining
Indicated in as 1 – Chaining to phase III (discussed in phase III Type I complex cognitive processing)

Figure 6.7. H2's Type II complex cognitive processing in phase II

In the structural element of phase II, H2 identified ions as polar molecules (attribute link) and the process involved as active transport (process link) while glucose and amino acids are large and polar molecules (attribute link) that move across the plasma membrane through facilitated diffusion (process link). However, when students were required to reason as to why the substances were absorbed into the human intestine, H2 reasoned that the movement of sodium ions, amino acids and fructose were through facilitated diffusion (process link) because all of them required transport proteins (attribute

link) which was revealed in his reasoning above. The following excerpt verified his mechanistic reasoning during the classroom discussion.

R	:	*Can sodium ion moves through the plasma membrane by active transport?*
H2	:	*No.*
R	:	*Why?*
H2	:	*Because ions will move from high concentration to low concentration in small intestines.*
R	:	*Do you mean there is no active transport in the small intestines?*
H2	:	*Hm…I think so.*

(H2, Excerpt from classroom discussion, Task 6 Phase II)

The attribute link in his reasoning for two different tasks of the same substances was different as H2 assumed that substances will always move across the plasma membrane in the small intestine via passive transport. For instance, he assumed that ions are always transported from a region of higher concentration to a region of lower concentration in the human small intestine. The contradiction of the attribute links in two different tasks suggested that there was invalid chaining between the structural and organisation elements.

Apart from the links which contradicted each other (as mentioned above), H2 had no problem in identifying and constructing the links as well as creating valid chaining between the elements. For example H2 was able to chain the osmosis process (process link) in the structural element in explaining the preservation of food and excessive fertilisers in plants in the organisation element.

In phase II, H2 managed to mostly generate accurate links as well as valid chaining. Therefore in phase II it can be said that H2 was at the Type II complex cognitive processing.

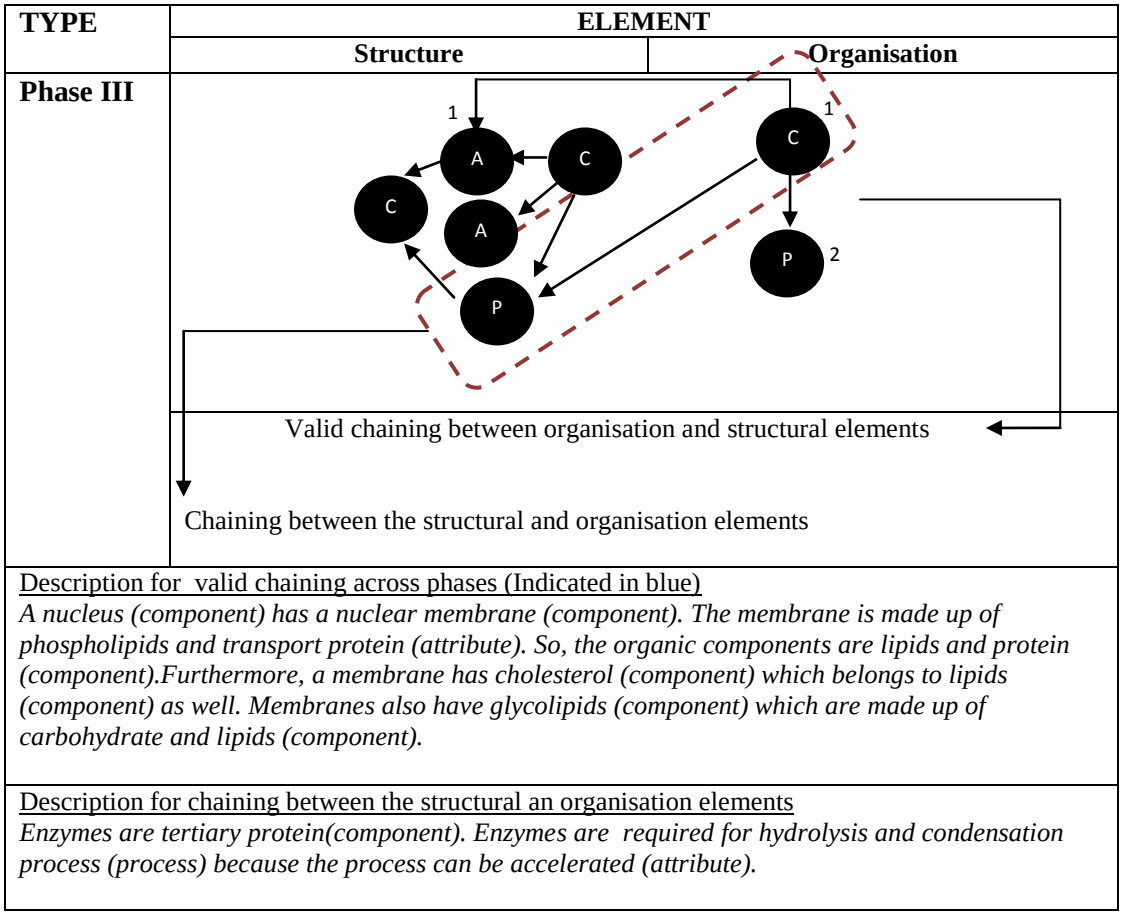


Figure 6.8. H2's Type II complex cognitive processing in phase III

In Figure 6.8, similar to phase II, there were no spoke or linear configurations formed in phase III. All the elements have chained which formed more than two network configurations. Despite the chaining within a phase, H2 also indicated chaining across the phases (which is indicated as '1' in Figure 6.8) and the chaining was valid. For instance, in phase I (as discussed earlier), H2 chained the component, the functional and attribute links in the structural element. As he progressed to phase III, he described further that the chemical substances that made up mitochondria are proteins and lipids because the membrane is made up of phospholipids bilayer and transport protein (chained to phase II).

In addition to the chaining across phases, he also demonstrated chaining between the elements by recognising the relationship between the enzyme's property (attribute link) in organisation element to the condensation and hydrolysis process in structural element. This can be verified in the excerpt below.

R	*:*	*Do you think enzymes are required for the hydrolysis and condensation process?*
H2	*:*	*I think yes.*
R	*:*	*Why?*
H2	*:*	*Because the process can be faster.*
R	*:*	*Why can the process be faster?*
H2	*:*	*Because enzymes can speed up the reaction (attribute).*

(H2, Excerpt from classroom discussion, Task 2 Phase III)

In the excerpt above, H2 was not only able to generate the attribute link of enzyme in organisation element (which is to speed up the reaction), but also chained it to the hydrolysis and condensation process (process link) in the structural element.

The chaining between the elements in a phase as well as across the phases indicated that H2's reasoning was classified as type II cognitive processing in phase III.

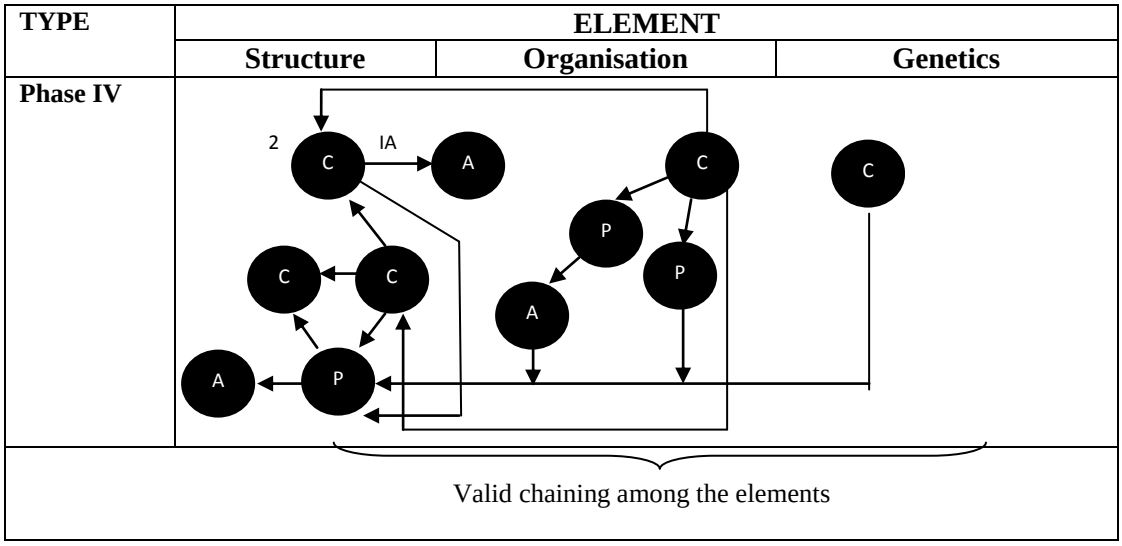


Figure 6.9. H2's Type II complex cognitive processing in phase IV

Valid chaining between the elements

The reason that caused this (non-disjunction) was because the chromosomes failed to separate (process). Thus, it produced gamete (process) which has abnormal number of chromosome (attribute). Cancer cells are formed when mutation occurs (process) in the nucleus. Then, the cell starts to divide uncontrollably (process).

The genetics of nerve cells and liver cells are similar because they are somatic cells that undergo mitosis (process). Mitosis produces genetically identical cells (attribute). So the genetics are similar. However, the genetics of a sperm and an ovum are different because of crossing over (process).

Chaining across phases (Indicated in blue 2)

This is chromatin (component) because it is a double helix of DNA (component link, chained to phase I) which can be found in the nucleus (component link, chained to phase I). This is the sister chromatid (component) because it is a chromosome in mitosis (inaccurate attribute). And homologous chromosome (component) consists of 2 chromosomes in meiosis (inaccurate attribute).

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 2 – Chaining to phase I

Figure 6.9. (Continued)

In Figure 6.9, there are no spoke or linear configurations formed in phase IV. All the elements are chained to form network configurations. The majority of the links were accurate except that which identified the attribute link for the different components such as chromatin, chromosome, sister chromatids and homologous chromosomes which is shown in Figure 6.9. Nonetheless, H2 was able to demonstrate valid chaining between the elements. For example, the formation of cancerous cells and the non-disjunction process in the organisation element were chained to the mitosis and meiosis process in structural element. Likewise, the genetics in different types of cells in the genetics element were also chained to the mitosis and meiosis processes in the structural element.

Table 6.5

H3's Overall Mechanistic Reasoning for the Theory of Cell

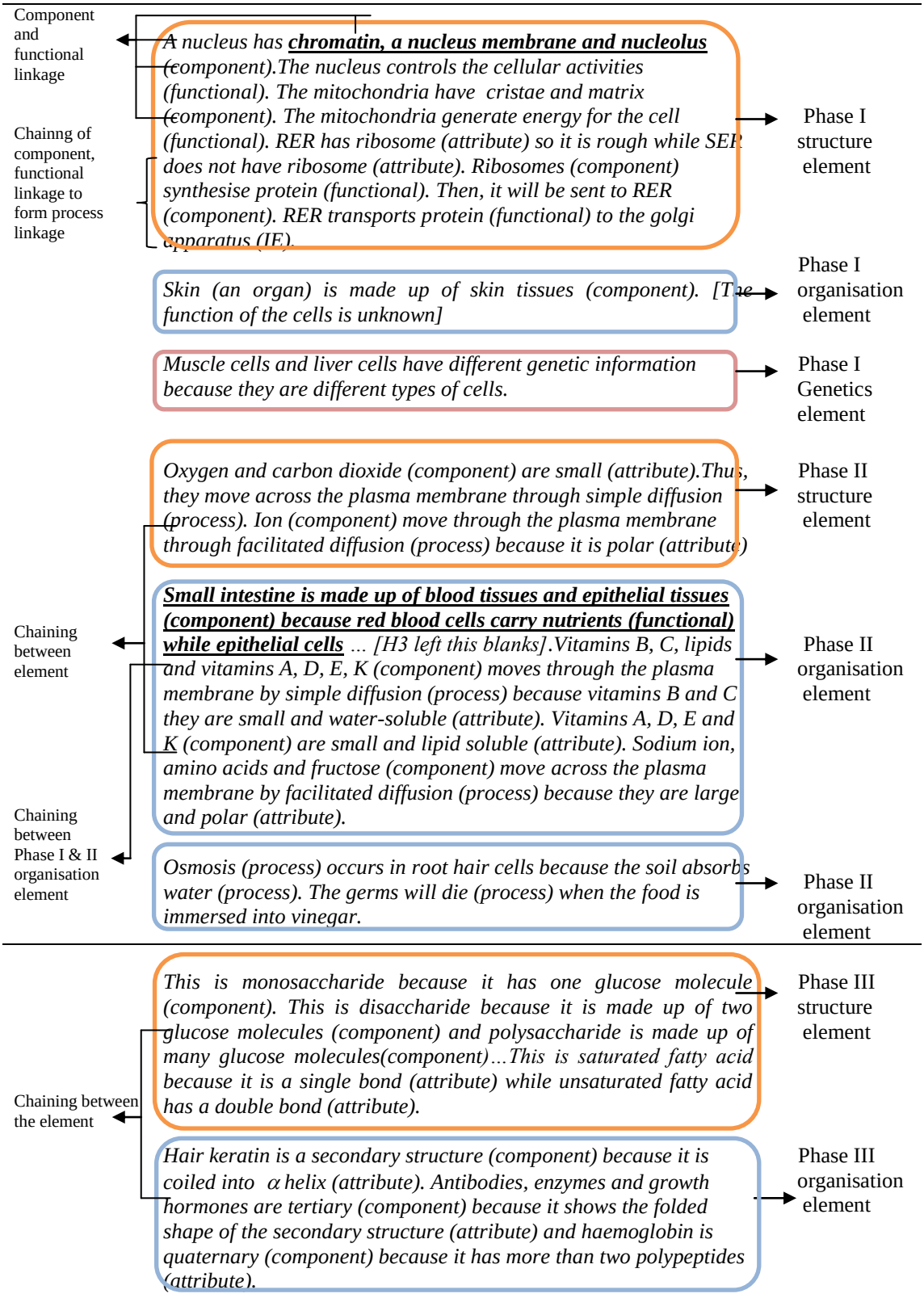


Table 6.5 (Continued)

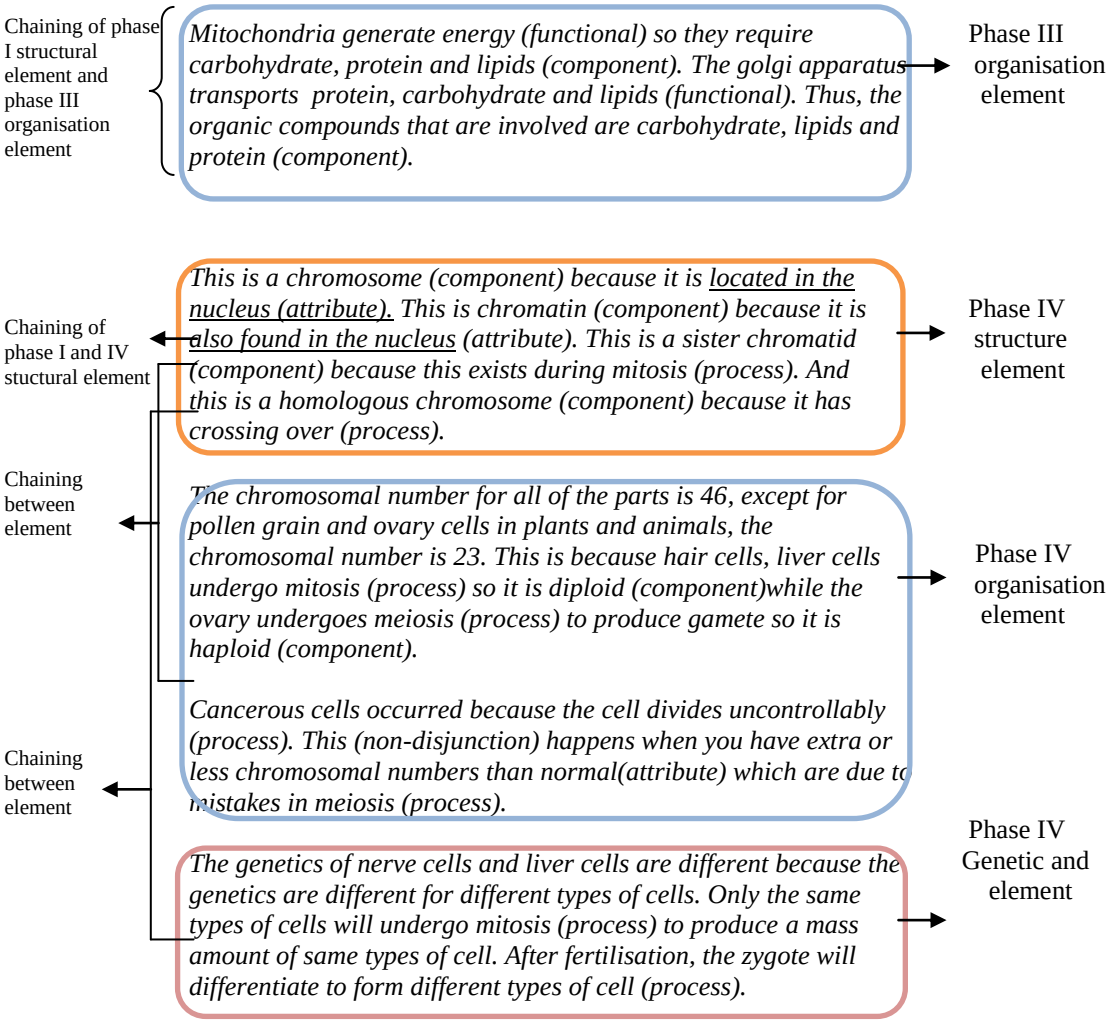


Table 6.5 shows H3's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by H3 comprises the component, attribute, functional and process links for the Theory of Cell in all the phases as shown in Table 6.5. How H3 has also managed to chain these links between the elements within a phase as well as across the phases is indicated in the table. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I, H3 demonstrated Type I simple cognitive

processing. In phases II and IV, he demonstrated Type I complex cognitive processing while in phase III he demonstrated type II simple cognitive processing. These will now be discussed.

Type I Simple Cognitive Processing

In phase I, which was the early part of H3's mechanistic reasoning, the component, attribute and functional links formed within each element could be classified as having spoke and network configurations. There was only one network configuration which was formed within the structural element. Some of the links were inaccurate especially the links in the organisation element. No chaining was formed between the elements. Thus, H3's reasoning is classified as Type I simple cognitive processing in phase I.

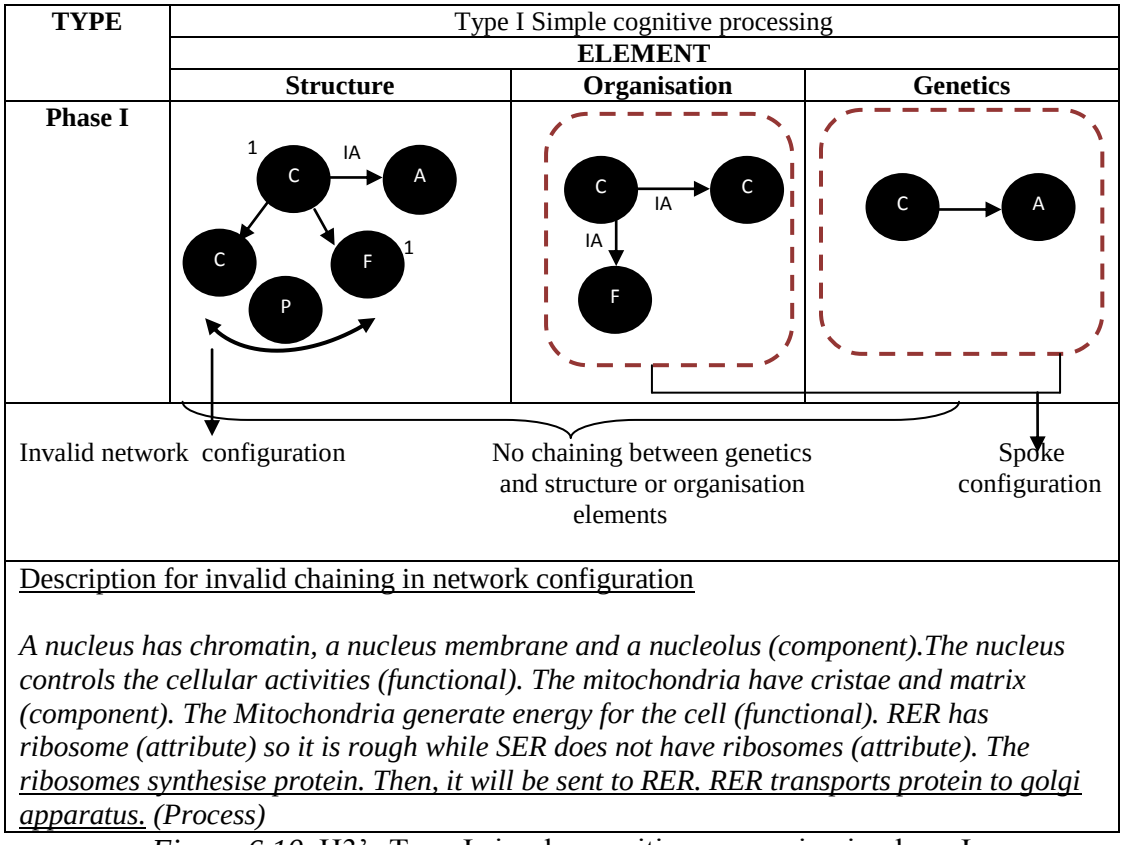


Figure 6.10. H3's Type I simple cognitive processing in phase I

Description for invalid chaining in the organisation element
Skin (an organ) is made up of skin tissues (component). [The function of the cells is unknown except for sperm cells]
Description for genetics element
Muscle cells and liver cells (component) have different genetic information because they are different types of cells (attribute).

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
Indicated as 1 – Chaining to phase III (discussed in Type II simple cognitive processing)

Figure 6.10. (Continued)

Based on Figure 6.10, most of the links were inaccurate. For example, the attribute link in the structural element. Even though prompting was given by the teacher, H3 was unable to provide the attribute link which is related to the component in the structural element. This is shown in the excerpt below.

R : Can you describe the property of the organelles you have mentioned?
H3 : Em…property…
R : What is the property for golgi apparatus? Describe the structure.
H3 : Em… transport proteins?
R : That's the function not the property.
H3 : Em…I don't know.

(Excerpt from classroom discussion)

As shown in the excerpt above, H3 gave the function of golgi apparatus which was to transport proteins instead of generating the attribute link of the organelle when he was prompted. As a result, there was no chaining generated by H3 between the structural and organisation elements. An example is shown in the following excerpt.

R : H3, can you explain the task.
H3 : Muscle cells require protein (inaccurate attribute), 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)

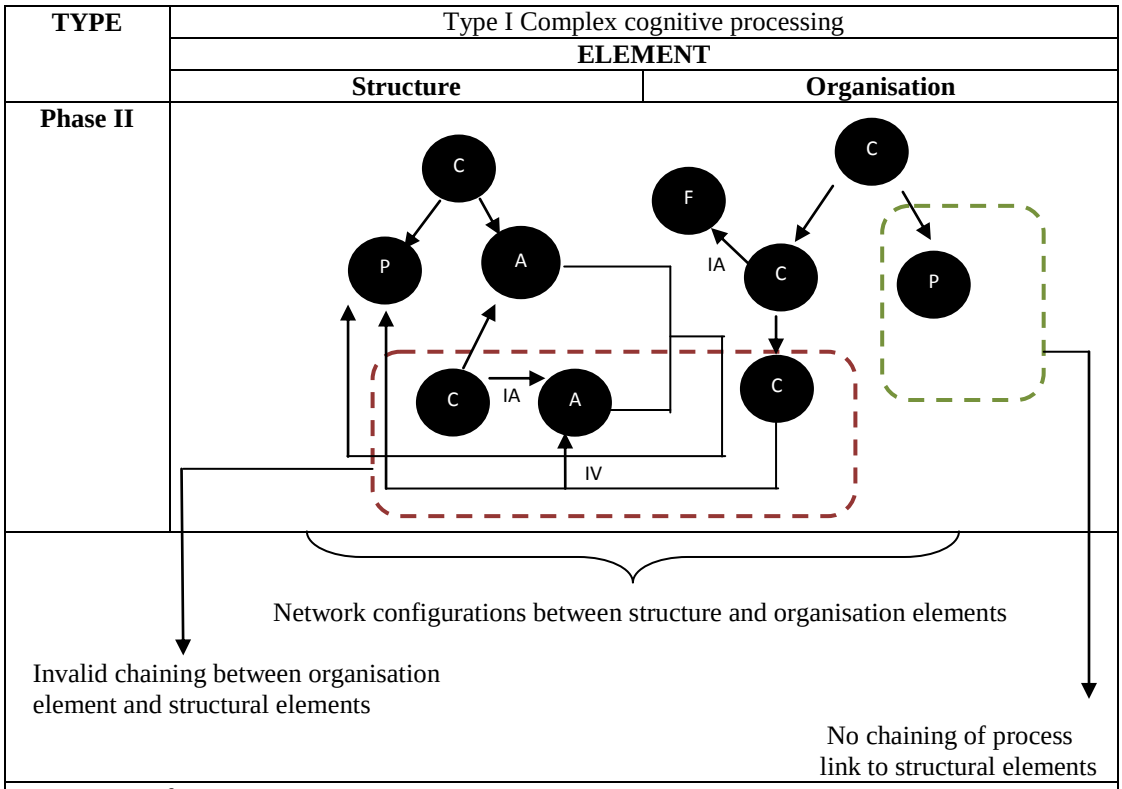
As shown in the excerpt above, H3 generated inaccurate links (muscle cells require a lot of proteins). Consequently, the chaining to the component link (RER) in structural element is invalid. H3 was also unable to state the functions of the pancreatic and liver cells in the organisation component. Thus, no chaining was constructed to the organelles that were found abundantly in those cells (structural element).

As for genetics element, H3 generated a linear configuration by generating the attribute link but failed to chain to the structural and organisation element.

Generally in phase I, H3 failed to generate accurate links especially in the organisation element. When he was further prompted by the researcher, most of the time the reason given was '*I don't know'.* It could be that the inaccurate links has led to a lack of chaining. Therefore in phase I it can be said that H3 was at Type I simple cognitive processing.

Type I Complex Cognitive Processing

In phases II, III and IV, the different types of links formed could be classified as having network configurations. The majority of the links were accurate; yet, the chaining between the configurations was invalid. Thus, H3's reasoning is classified as Type I complex cognitive processing in phases II, III and IV. This is shown in Figure 6.11.



Description for invalid chaining between organisation element and structural element

The transport of the substances is all about passive transport because they move from high to low concentration. Written Task 1

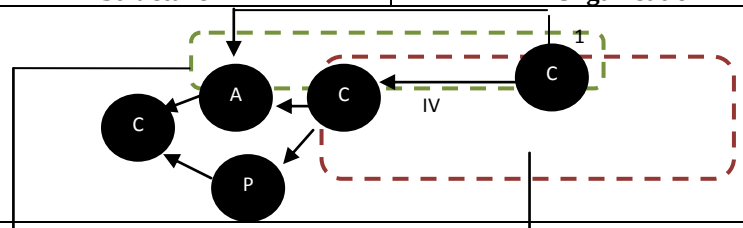
Sodium ions, amino acids and fructose (component) move through the plasma membrane by facilitated diffusion (process) because they are large and polar (attribute). Written task 6

Description for chaining across phases

The small intestines are made up of red blood cells (component) and epithelial cells (component). The red blood cells carry nutrients (functional) while epithelial cells … (H3 left this blanks)

Description for no chaining of process link to structural element
The germs will die because the solution is too sour. (Food preservation)

Figure 6.11. H3's Type I complex cognitive processing in phases II, III and IV

<table>
<tr><td>TYPE</td><td>Type I Complex cognitive processing</td></tr>
<tr><td></td><td>ELEMENT</td></tr>
<tr><td></td><td>Structure | Organisation</td></tr>
<tr><td>Phase III</td><td> 
</td></tr>
<tr><td></td><td>Valid chaining between the elements
Invalid chaining across phases</td></tr>
<tr><td></td><td><u>Description for no chaining aross phases</u>

Mitochondria generate energy (functional) so they require carbohydrates, proteins and lipids (component). The golgi apparatus transports protein, carbohydrates and lipids (functional). Thus, the organic compounds which are involved are carbohydrates, lipids and proteins (component).</td></tr>
<tr><td></td><td><u>Description for valid chaining between the elements</u>

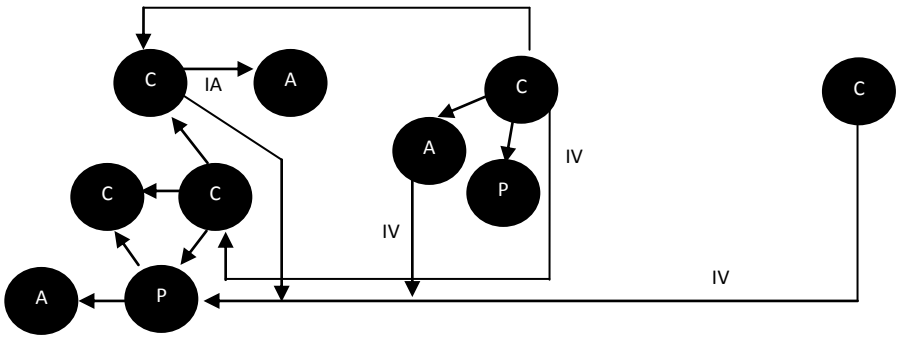
Hair keratin is a secondary structure (component) because it is coiled into helix (attribute). Antibodies, enzymes and growth hormones are tertiary (component) because they show the folded shape of a secondary structure (attribute) and haemoglobin is quaternary (component) because it has more than two polypeptides (attribute).</td></tr>
<tr><td>TYPE</td><td>ELEMENT</td></tr>
<tr><td></td><td>Structure | Organisation | Genetics</td></tr>
<tr><td>Phase IV</td><td> 
</td></tr>
<tr><td></td><td>Invalid chaining between organisation, structural and genetics elements</td></tr>
</table>

Figure 6.11. (Continued)

Invalid chaining between the structural and genetics elements

The genetics of nerve cells and liver cells are different because the genetics are different for different types of cells. Only same types of cells will undergo mitosis (process) to produce mass amount of the same types of cell. After fertilisation, the zygote will differentiate to form different types of cell (process)

Invalid chaining between organisation and structural elements

Cancerous cell due to the cell divides uncontrollably (process)… This (non-disjunction) happens when you have extra or less chromosomal numbers than normal(attribute) which is due to mistakes in meiosis

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III

Figure 6.11. (Continued)

Based on Figure 6.11, H3 still generated some inaccurate links in phase II and IV especially the attribute links. For instance, in the written task 1 in phase II, H3 assumed that all substances move across the plasma membrane by passive transport because they move from a region of higher concentration to a region of lower concentration (attribute link). Although in written task 6 he was able to state more precisely the process and attribute links which are the substances that are large and polar will be transported through the plasma membrane through facilitated diffusion, he still believed that all the substances should move from a high to low concentration which is shown in the following excerpt.

R : *Does active transport occur in the small intestine?*
H3 : *No.*
R : *Why?*
H3 : *Because substances move from high to low.*
R : *What do you mean by substances move from high to low?*
H3 : *Hm…I think is from many substances from one place to one place which has less substances.*

(H3, Excerpt from classroom discussion, Task 6 Phase II)

As can be seen in the excerpt above, H3 assumed that substances will move from a low to high region of concentration in the small intestine. Similarly in the organisation

element of phase II, the functional link was left blank by H3, for example, the function of the epithelium cell.

Although H3 attempted to construct more chaining in his mechanistic reasoning in phase II and phase IV, much of the chaining was invalid. For example, in explaining food preservation (process link), H3 was unable to chain to any links in the structural component. This was further validated during the classroom discussion as shown below.

R : How will germs die when the food is immersed into vinegar?
H3 : Em…because it is too sour.
R : Then?
H3 : Then...the germs cannot live in a sour condition.

(Excerpt from classroom discussion)

As shown in the excerpt above, when H3 was asked to reason why the food had to be immersed into vinegar, he reasoned that the germs could not live in a sour condition which indicated no chaining to the osmosis concept in the structural element.

H3's mechanistic reasoning indicated a lack of valid chaining especially between the organisation and genetics elements which had probably hindered him from progressing to type II complex cognitive processing.

In phase III, very few links were identified although the links were accurate. H3 seemed to encounter difficulties in constructing different types of links in phase III as compared to phases II and IV.

H3 demonstrated network configurations between the elements and across the phases; yet, the chaining across the phases that contributed to the network configuration was invalid. For example, he chained the chemical composition of the organelle to its function (functional link) instead of the structure of the organelle (attribute link) in Figure

6.11. Therefore, he was only able to chain between phase I and phase III which is shown in Figure 6.11.

In phase IV, H3 also failed to construct any chaining in describing a phenomenon in the organisation element when he was asked to explain further. This is shown in the excerpt below which is related to the formation of cancerous cells.

R : How do cells divides uncontrollably?
H3 : There is something wrong with the cell.
R : What's wrong with the cell?
H3 : Hm...I don't know. Maybe like human, suddenly goes crazy.

(Excerpt from classroom discussion)

As for the genetics element in phase IV, H3 still thought that the genetic composition of different types of cell was different even though he had learnt the cell division process. Although the reasoning showed chaining to mitosis and meiosis in the structural element, the chaining was invalid as he assumed that only the same type of cells will undergo mitosis to form new type of cells.

Hence in phases II and IV, H3 for most of the time managed to generate accurate links although there were few inaccurate ones. Chaining between the elements was attempted by H3, and more than two network configurations were formed; yet, the chaining was invalid. Therefore in phases II and IV it can be said that H3 was at Type I complex cognitive processing.

Table 6.6

H4's Overall Mechanistic Reasoning for the Theory of Cell

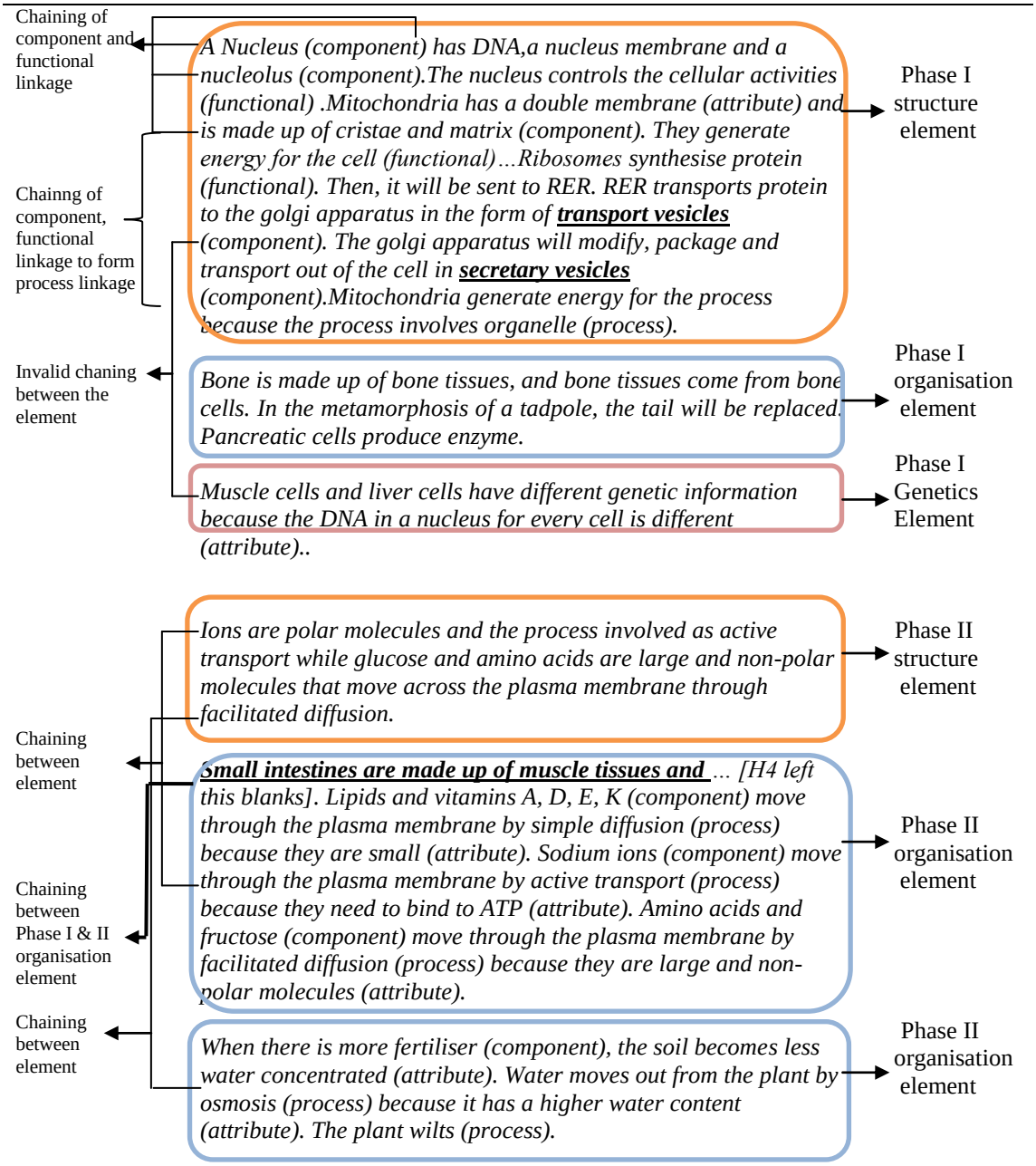


Table 6.6 (Continued)

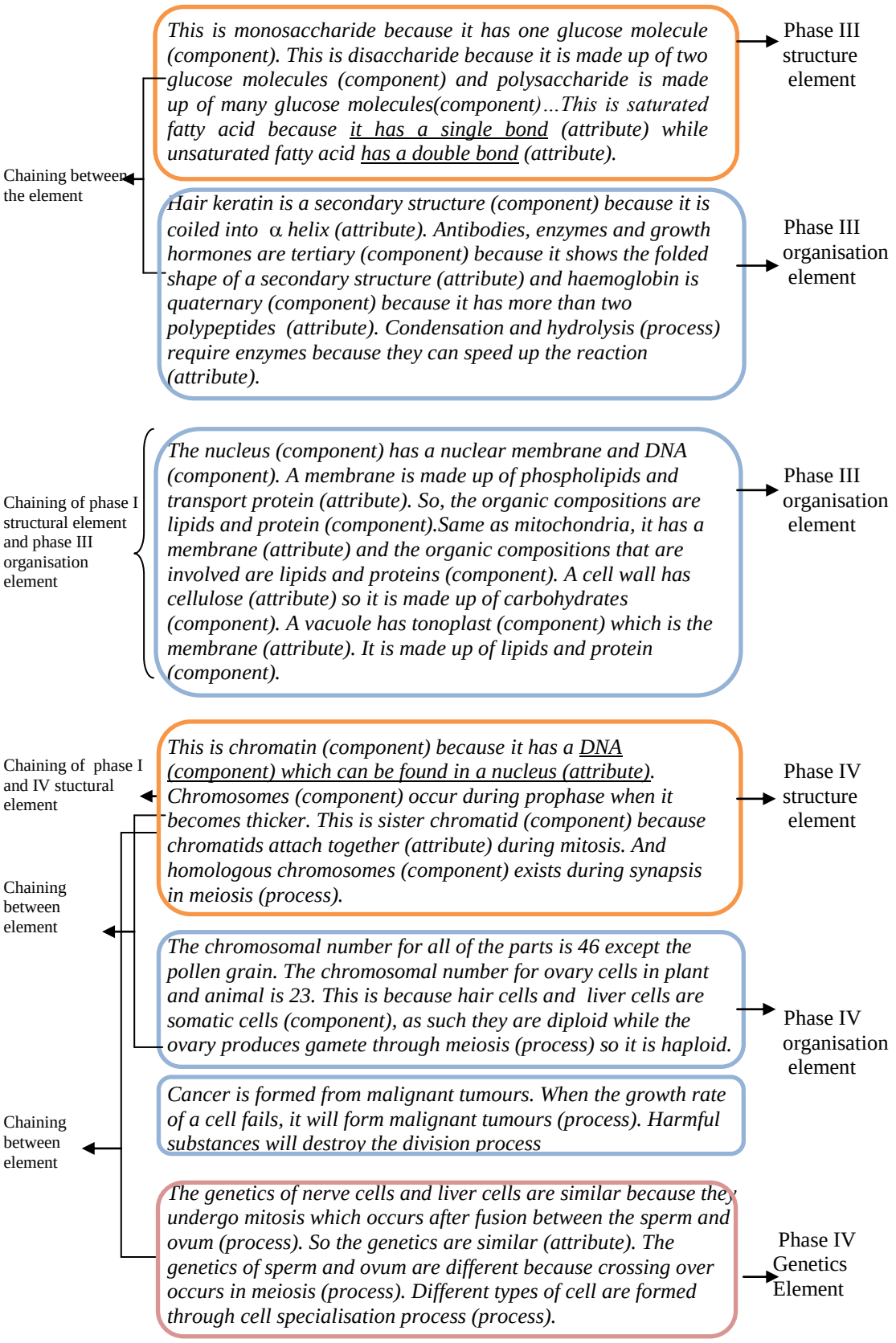
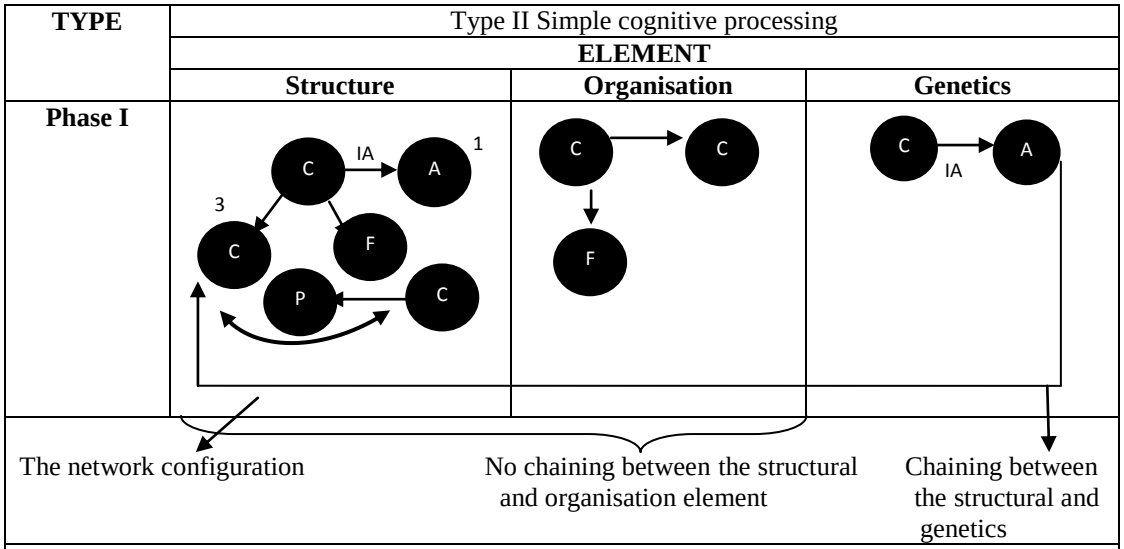


Table 6.6 shows H4's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by H4 comprises the component, attribute, functional and process links for the Theory of Cell in all the phases which are also shown in Table 6.6. How H4 managed to chain these links between the elements within a phase as well as across phases is indicated in the table. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I, H4 demonstrated Type II simple cognitive processing and in phase II, H4 demonstrated Type I complex cognitive processing. In phases III and IV, H4 demonstrated Type II complex cognitive processing. These will now be discussed.

Type II Simple Cognitive Processing

In phase I, which was the early part of H4's mechanistic reasoning, the component, attribute and functional links formed within each element could be classified as having spoke and network configurations. There are two network configurations which were formed within the structural element and between the structural and genetics elements respectively. A few of the links were inaccurate. Thus, H4's reasoning is classified as Type II simple cognitive processing. This is shown in Figure 6.12.



Description for network configuration in the structural element

A nucleus (component) has DNA, a nucleus membrane and a nucleolus (component).The nucleus controls the cellular activities (functional). The mitochondria has a double membrane (attribute) and is made up of cristae and matrix (component). They generate energy for the cell (functional)…Ribosomes synthesise protein. Then, it will be sent to RER. RER transports protein to the golgi apparatus in the form of transport vesicles (component). The golgi apparatus will modify, package and transport out of the cell in secretary vesicles (component). The mitochondria generate energy for the process because the process involves organelle (process).

Description for no chaining between structural and organisation element

Bone is made up of bone tissues, and bone tissues come from bone cells (component). In the metamorphosis of a tadpole, the tail will be replaced (function). Pancreatic cells produce enzymes. (function)

Description for chaining between structural and gene and generation of new cells

Muscle cells and liver cells have different genetic information because the DNA in the nucleus for every cell is different (attribute).

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1,3 – Chaining to phase II and IV (discussed in phase III and IV Type II complex cognitive processing)

Figure 6.12. H4's Type II simple cognitive processing in phase I

Based on Figure 6.12, many of the links within each element were accurate. Although H4 recognised the function of the cells in the organisation element, he could not provide a valid chaining to the structural element even though classroom discussion had been carried out. This was elucidated in the following excerpt.

H4 : … In the metamorphosis of a tadpole, the tail will be replaced, so…(silence)
R : So? What organelle was found abundantly?
H4 : I am not sure…
R : Alright, next. Pancreatic cells.
H4 : Pancreatic cells produce enzymes (functional)…em…(silence) Sorry teacher, I don't know.

(Excerpt from classroom discussion)

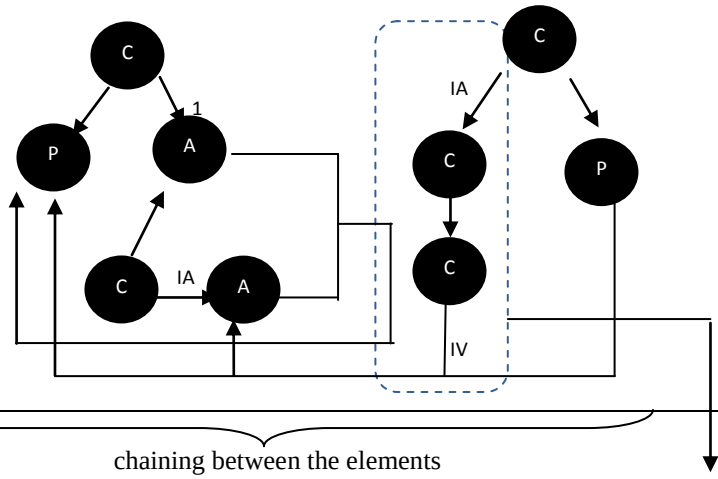
The above excerpt indicated that H4 was unable to chain between the structural and organisation elements. For example, H4 was only able to identify that pancreatic cells produce enzymes (functional link) but he failed to identify the attribute link of enzymes which is a type of protein. This appeared to hinder him from chaining to the structural element.

Similarly in the genetics element, he tried to chain the genetic information with the role of the nucleus. However, H4 appeared to be unable to identify the related process link which is cell specialisation in the structural element. Hence, H4 failed to construct valid chaining to the structural and organisation elements. In addition, the attribute link generated by H4 which was 'DNA in the nucleus is different in different types of cells' was inaccurate. It appears that without appropriate links (such as component, attribute, functional and process) in elucidating mechanistic reasoning, one might be unable to proceed to complex cognitive processing as lack of chaining is being constructed when links are inaccurate.

Hence in phase I, H4 for most of the time managed to generate accurate links. In addition, chaining between the elements was attempted by H4, and network configurations were formed; yet, the chaining was invalid. Therefore in phase I it can be said that H4 was at Type II simple cognitive processing.

Type I Complex Cognitive Processing

In phase II, there is chaining between the structural and organisation elements that formed the network configurations. The majority of the links were accurate; yet, the chaining that formed the network configuration was invalid. Thus, H4's reasoning is classified as Type I complex cognitive processing. This is shown in Figure 6.13.

TYPE	Type I Complex cognitive processing	
	ELEMENT	
	Structure	**Organisation**
Phase II		
Description for invalid chaining between structural and organisation elements *Amino acids move across the plasma membrane by facilitated diffusion because they are big and non-polar. Ion s are polar thus the molecules will move across the plasma membrane through active transport.* Written task 1 *Sodium ions (component) moves through the plasma membrane by active transport (process) because they need to bind to ATP (attribute). Amino acids and fructose (component) move through the plasma membrane by facilitated diffusion (process) because they are large and non-polar molecules (attribute).*Written task 6 *Small intestines are made up of muscle tissues and… [H4 left this blanks, organisation element]*		
Valid chaining between structural and organisation elements *When there is more fertiliser, the soil becomes less water concentrated. Water moves out from the plant by osmosis because it has a higher water content. The plant wilts (process).*		

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III (discussed in phase III Type II complex cognitive processing)

Figure 6.13. H4's Type I complex cognitive processing in phase II

Based on Figure 6.13, many of the links within each element were accurate. However, some chaining was invalid due to inaccurate links. For example, H4 identified ions as polar molecules and the process involved as active transport. On the other hand, glucose and amino acids are large, non-polar molecules that move across the plasma membrane through facilitated diffusion. During the classroom discussion, he explained that only ions can be transported via active transport because only polar molecules will move across the plasma membrane through active transport. This is inaccurate as some amino acids are also polar molecules. As a result, when students were required to reason the substances that were absorbed into the human intestines (organisation component) in another task, H4 still insisted the movement for sodium ions is active transport and glucose is via facilitated diffusion.

Besides that, he was unable to identify links such as component and functional links in describing the different types of tissues that make up an organ. This was indicated in the following excerpt.

R : What types of tissues are small intestine made up of?
H4 : Muscle tissues and... (silence)
R : Only muscle tissues?
H4 : Em… blood tissue.
R : What else?
H4 : I forgot the name of other tissues.

(Excerpt from classroom discussion)

Based on the excerpt above, although H4 was able to state that the small intestine is made up of different tissues, yet he failed to identify the types of tissues (component links) in the small intestines.

However, H4 was able to chain the process link in the organisation element to the structural element precisely. For example, H4 was able to chain the consequences of

excessive fertiliser in soil (process link) in the organisation component to osmosis (process link) in the structural element which is indicated in Figure 6.13.

Hence in phase II, H4 for most of the time managed to generate accurate links. In addition, chaining between the elements was attempted by H4, and several network configurations were formed; yet, the chaining was invalid. Therefore in phase II it can be said that H4 was at Type I complex cognitive process.

Type II Complex Cognitive Processing

In phases III and IV, which were the last two phases of H4's mechanistic reasoning, the different types of links formed could be classified as having network configurations between the elements as well as across the phases. All the links generated were accurate and the chaining was valid. Thus, H4's reasoning is classified as Type II complex cognitive processing for the last two phases.

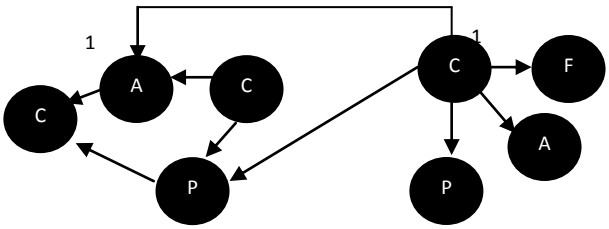
<table>
<tr><td rowspan="3">TYPE</td><td colspan="2">Type II Complex cognitive processing</td></tr>
<tr><td colspan="2">ELEMENT</td></tr>
<tr><td>Structure</td><td>Organisation</td></tr>
<tr><td>Phase III</td><td colspan="2"> 
</td></tr>
<tr><td></td><td colspan="2">Valid chaining between organisation element and structural element</td></tr>
<tr><td colspan="3"><u>Description for valid chaining across phases (Indicated in blue)</u>
A nucleus (component) has a nuclear membrane and DNA (component). A membrane is made up of phospholipids and transport protein (attribute). So, the organic compositions are lipids and protein (component).Same as mitochondria, it has a membrane (attribute) and the organic compositions which are involved are lipids and protein (component). A cell wall has cellulose (attribute) as such it is made up of carbohydrates (component). A vacuole has tonoplast (component) which is the membrane (attribute). It is made up of lipids and protein (component).</td></tr>
</table>

Figure 6.14. H4's Type II complex cognitive processing in phase III and IV

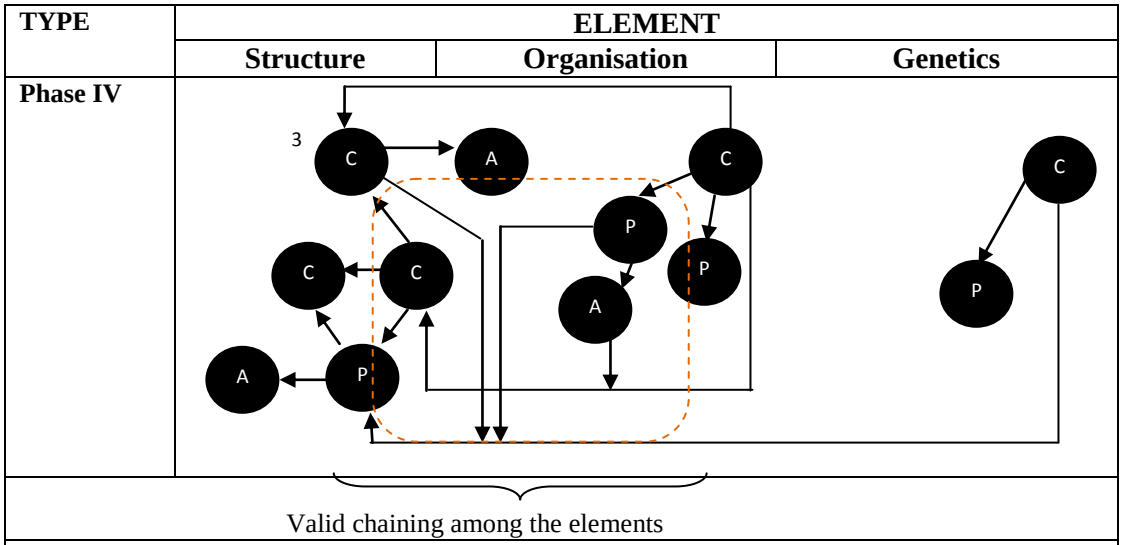


Figure 6.14. (Continued)

Based on Figure 6.14, H4 was able to generate different types of accurate links and the links were chained between the elements. Thus, H4 showed a higher number of chaining in his reasoning in phases III and IV. For instance, when students were required to state the organic compound of certain organelles in the organisation element of phase III, H4 chained the organelle (component), for example mitochondria, to its property/ attribute link (have double membrane, phase I). He further described that the organic compounds that were made up of mitochondria are proteins and lipids as the membrane of the

mitochondria is made up of phospholipids bilayer and transport protein (phase II). This is indicated in the chaining across phases I, II and III.

Similarly in phase IV, H4 was able to provide accurate links and the links were chained between the elements as well as across the phases which are shown in Figure 6.14. For example, H4 chained the attribute link of mitosis and meiosis in the structural component to the genetics element (chaining forward). In addition, he was also able to chain backward on how different types of cells are formed after the mitotic process to the process which is known as cell specialisation. This is supported by the excerpt below.

R : How are different types of cells formed if the genetics are similar?
H4 : Through a cell specialisation process (process).
R : What is cell specialisation?
H4 : The cells differentiate to form different types of cell (process).

(H4, Excerpt from classroom discussion, Task 4 Phase IV)

Based on the above excerpt, H4 was able to reason out the genetics of different types of cell by chaining to the mitotic process in the structural element (phase IV) and also chain it to the process link (cell specialisation) of the structural element in phase I.

Generally, H4 revealed more valid chaining within a phase as well as across phases as he reached phases III and IV. H4 was also able to generate accurate links within a phase. Therefore in phases III and IV, it can be said that H4 was at Type II complex cognitive processing.

Table 6.7

L1's Overall Mechanistic Reasoning for the Theory of Cell

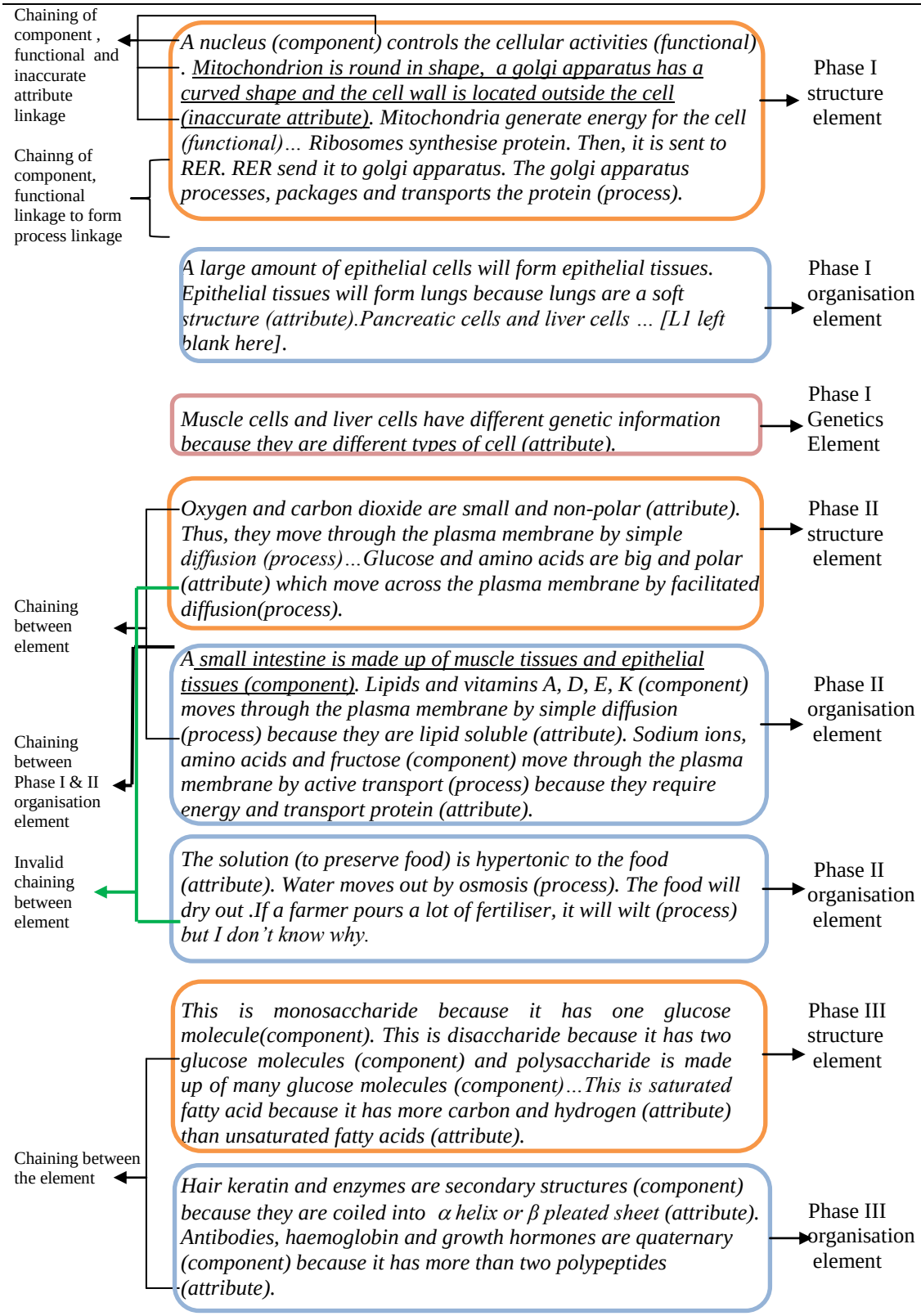


Table 6.7 (Continued)

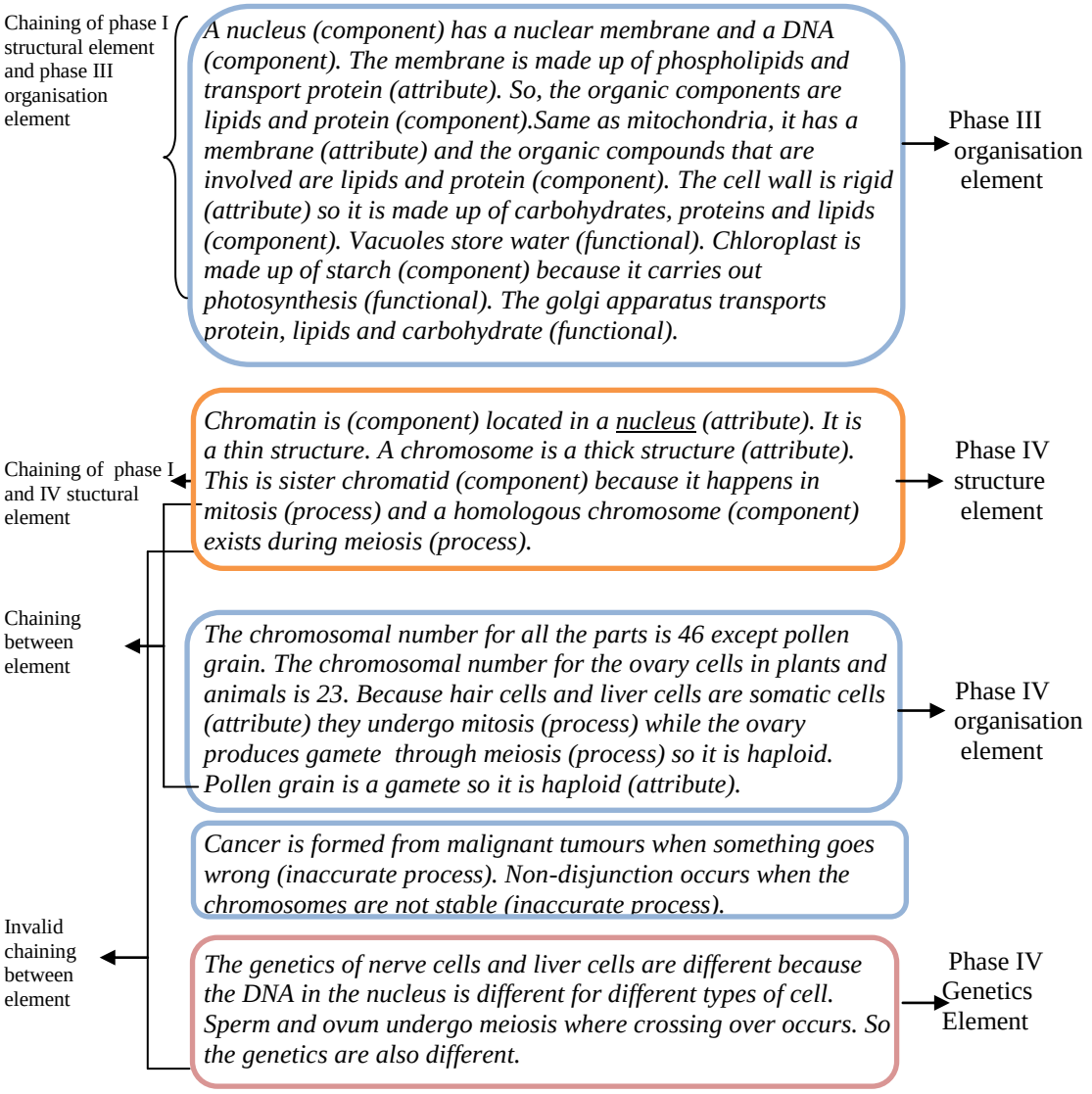


Table 6.8

L2's Overall Mechanistic Reasoning for the Theory of Cell

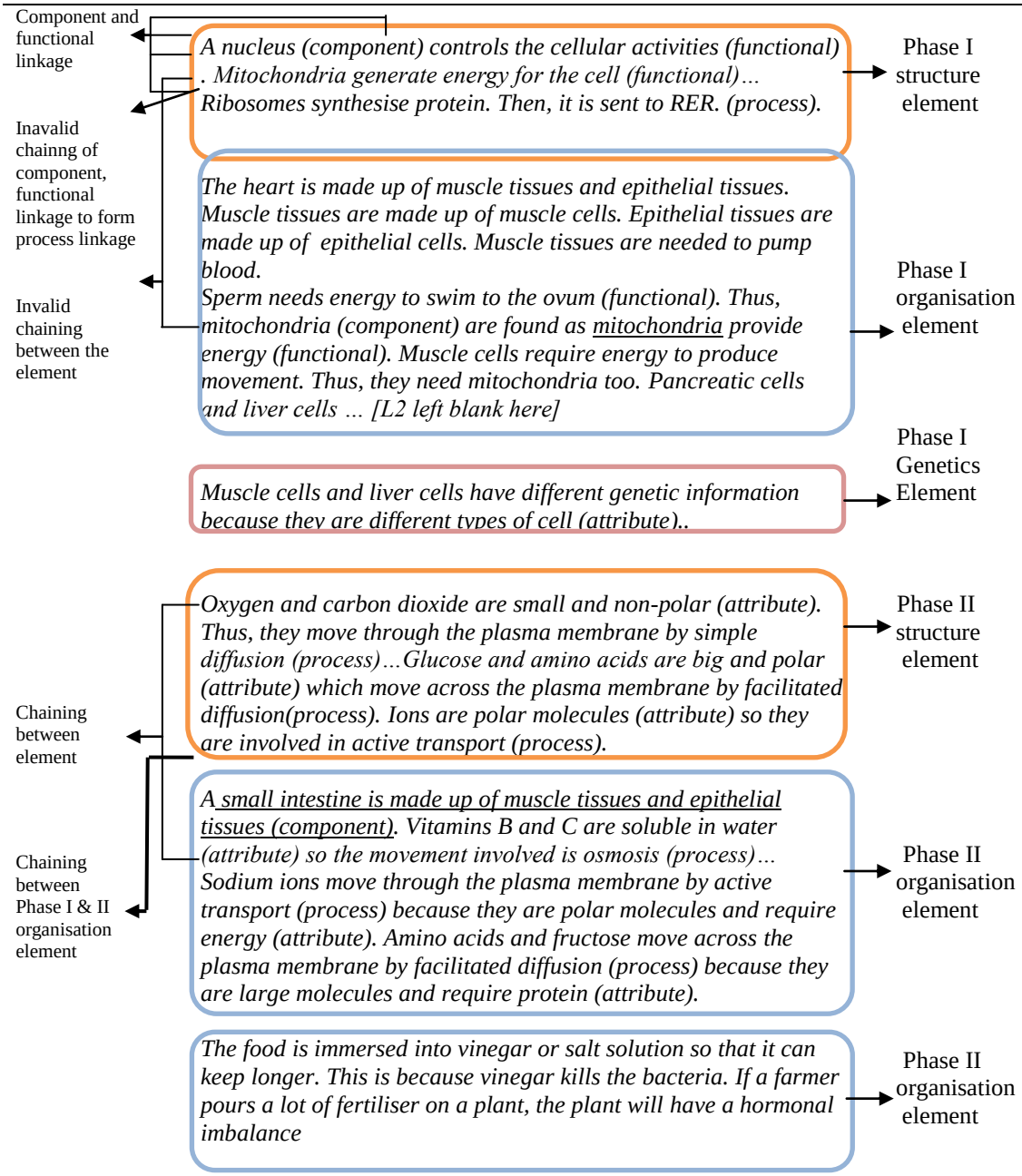


Table 6.8 (Continued)

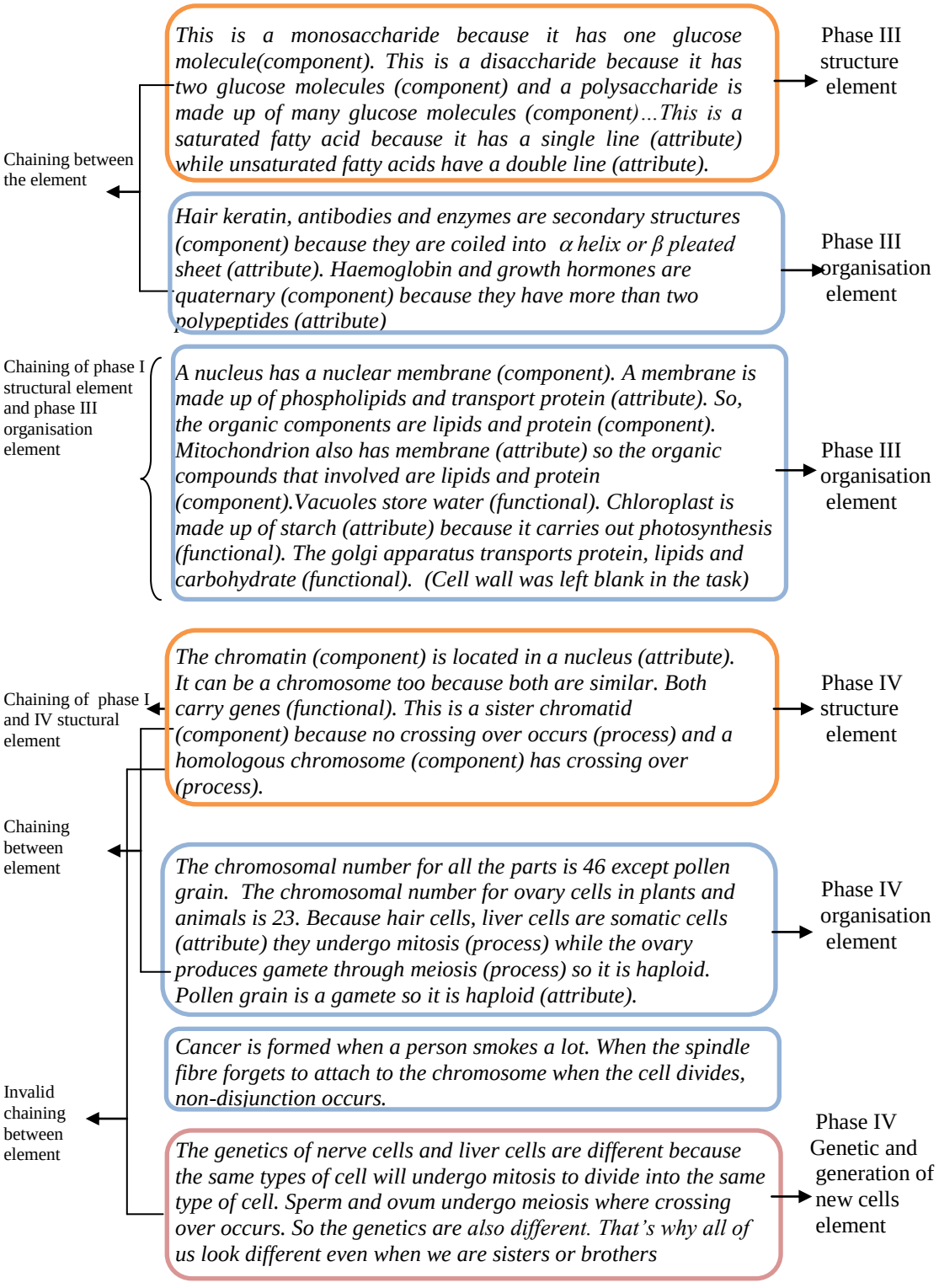


Table 6.9

L4's Overall Mechanistic Reasoning for the Theory of Cell

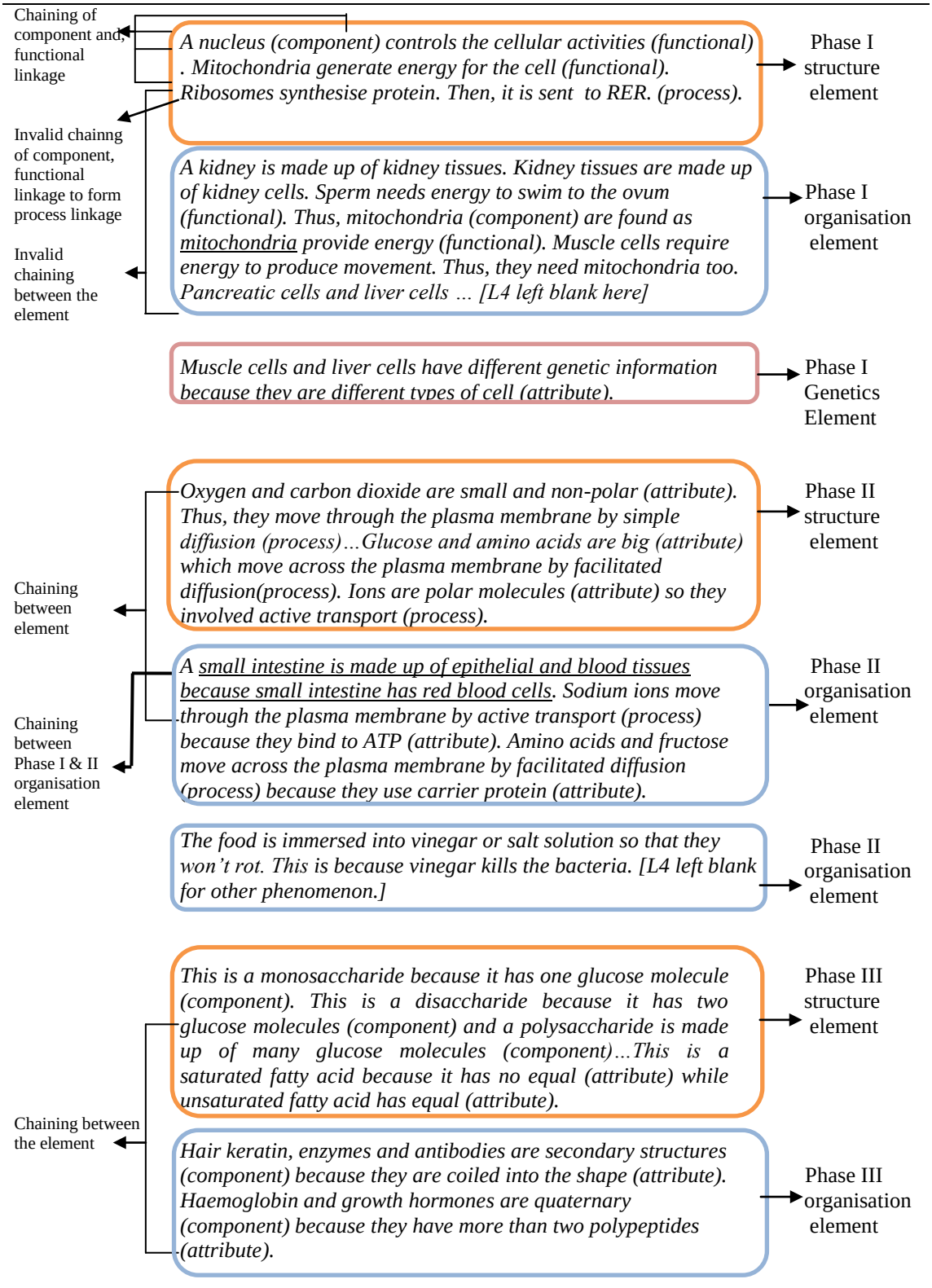
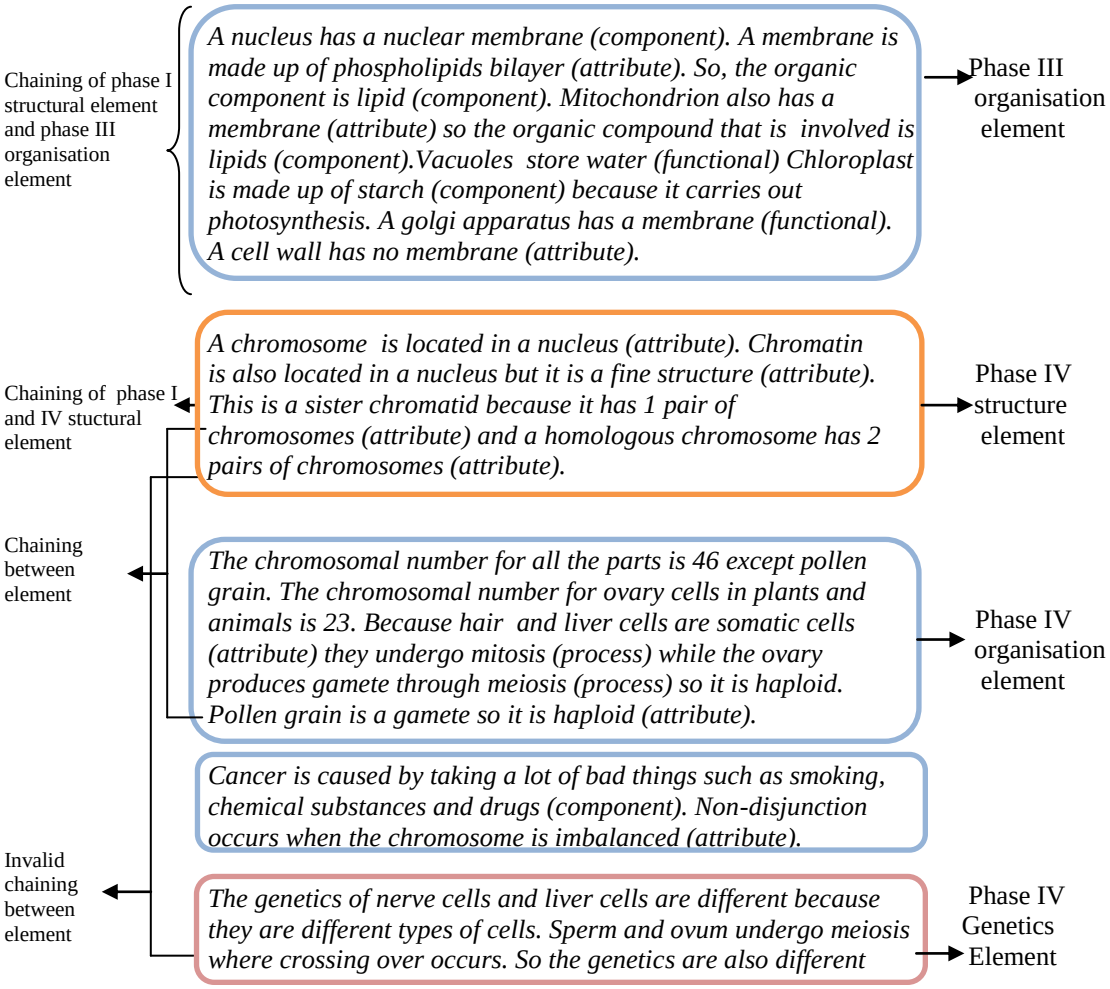


Table 6.9 (Continued)



Tables 6.7, 6.8 and 6.9 show L1, L2 and L4's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by L1, L2 and L4 comprise the component, attribute, functional and process links for the Theory of Cell in all the phases as shown in Tables 6.7, 6.8 and 6.9. How L1, L2 and L4 have also managed to chain these links between the elements within a phase as well as across phases are indicated in the tables. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I, L1, L2 and L4 demonstrated Type I simple cognitive processing and in phases II to IV,

L1, L2 and L4 demonstrated Type I complex cognitive processing. These will now be discussed.

Type I Simple Cognitive Processing

In phase I (Figure 6.15), the component, attribute and functional links formed within each element could be classified as having spoke and network configurations. There was a network configuration which was formed within the structural element which was generated by L1. L2 and L4 generated either spoke or liner configurations within an element. Some of the links were inaccurate especially the links in the organisation element. There was no chaining demonstrated by L1, L2 and L4 between the elements. Thus, their reasoning is classified as Type I simple cognitive processing. This is shown in Figure 6.15.

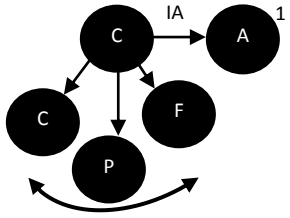
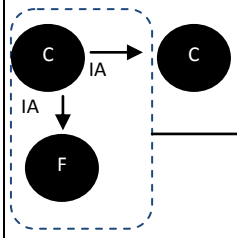
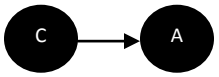
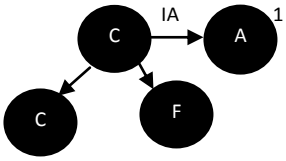
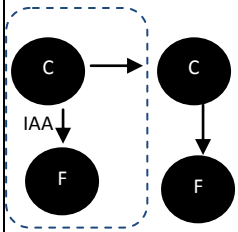
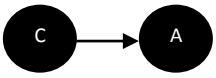
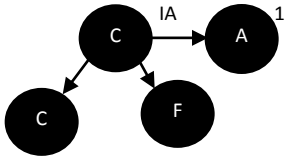
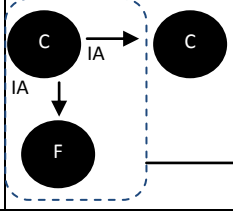
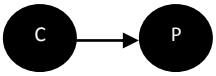
Student	Type I Simple cognitive processing			**Description**
	ELEMENT			
	Structure	**Organisation**	**Genetics**	
L1				1. No chaining among three elements 2. Inaccurate links 3. Comprises only spoke or linear configurations
L2				
L4				Inaccurate links in organisation component

Figure 6.15. L1, L2 and L4's Type I simple cognitive processing in phase I

Description for inaccurate attribute link in structural element *A nucleus (component) controls the cellular activities (functional) . Mitochondria generate energy for the cell (functional)…*[No desscription of attribute link] … *RER has ribosomes that transport protein.* [L2 and L4 Written Task] *A nucleus (component) controls the cellular activities (functional) . Mitochondria is found in round shape (attribute) that generate energy for the cell (functional). The golgi apparatus is curve shaped (attribute)…*[L1 Written task]
Description for invalid chaining between the organisation and structural component *Sperm needs energy to swim to the ovum (functional). Thus, mitochondria (component) are found as mitochondria provide energy (functional). Pancreatic cells and liver cells …* [L1, L2 & L4 left blank for pancreatic and liver cells]
Description for the genetics element *Muscle cells and liver cells have different genetic information because they are different types of cell (attribute)*. (L1 & L2) *Muscle cells and liver cells have different genetic information because they are formed by different processes* (process). (L4)

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III and IV (discussed in phase III Type I complex cognitive processing)

Figure 6.15. (Continued)

Based on Figure 6.15, the functional and component links in the organisation element were mostly inaccurate. For example, in the organisation element such as cell organisation in phase I, the functional link for the different types of cell was inaccurate. The reasoning given by L1 and L4 was rather intuitive than scientific based which was revealed in the excerpt below:

R : Why are lungs made up of epithelial tissues?
L1 : Epithelial tissues will form lungs because lungs are a soft structure.
…
R : Why is a kidney made up of kidney tissues?
L4 : Because it is kidney.
R : Can you elaborate?

L4 : Like skin is made up of skin tissues, the heart has heart tissues. As such, a kidney should have kidney tissues.

(L1 & L4, Excerpt from classroom discussion, Task 3)

Based on the excerpt above, L1 reasoned that epithelial tissues will form lungs because it is soft instead of generating an accurate functional link which acts as a protective layer for the lung. Similarly, L4 reasoned that every organ has its own tissues, for example the heart should have heart tissues, instead of generating related links. There was also no chaining constructed between the structural and organisation elements. In the genetics element, all of them did not chain to the structural and organisation elements. Three of them assumed that the genetics were different either due to the different types of cells or due to different formation processes (Figure 6.15).

Hence in phase I, L1, L2 and L4 generated some inaccurate links especially in the organisation element. In addition, no chaining was formed between the elements Therefore in phase I, it can be said that L1, L2 and L4 was at Type I simple cognitive processing.

Type I Complex Cognitive Processing

From phases II to IV, L1, L2 and L4 demonstrated more accurate links and attempted more instances of chaining between the elements within a phase to form more network configurations. However, several links and chains were inaccurate. In phase II, L1, L2 and L4 revealed contradictions in the links generated. This is indicated in Figure 6.16 and discussed in more detail.

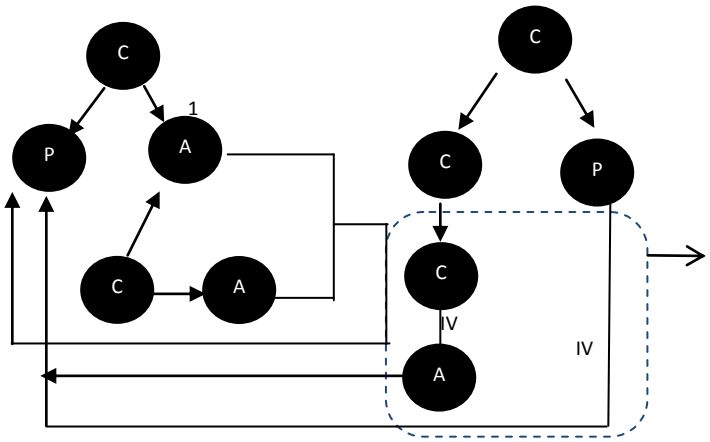
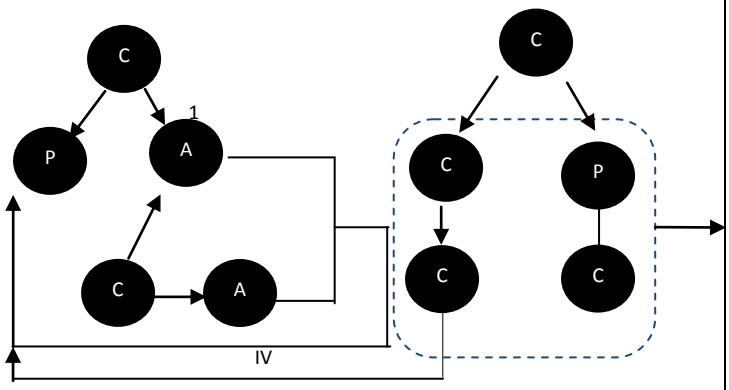
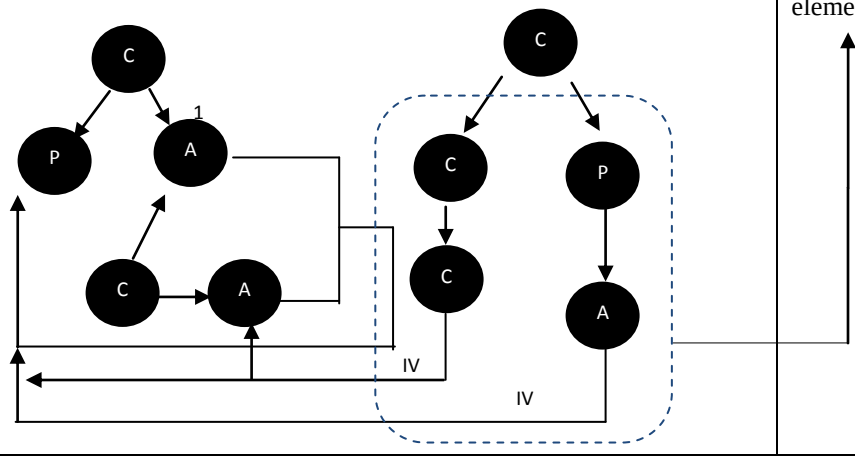
Student	Type I Complex cognitive processing	Description
	ELEMENT	
	Structure / **Organisation**	
L1		1. Network configurations. 2. Invalid chaining between structural and organisation element.
L2		1. Network configurations. 2. Invalid chaining between structural and organisation element.
L4		

Figure 6.16. L1, L2 and L4's Type I complex cognitive processing in phase II

Description for invalid chaining between the structural and organisation elements

Lipids and vitamins A, D, E, K (component) moves through the plasma membrane by simple diffusion (process) because they are lipid soluble (attribute). Sodium ions, amino acids and fructose (component) move through the plasma membrane by active transport (process) because they require energy and transport protein (attribute). [L1's written task]

If a farmer pours a lot of fertiliser, it will wilt (process) but I don't know why. [L2's written task]

Description for chaining across phases

Small intestines are made up of muscle tissues (component) and epithelial tissues (component). [L1's written task]

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III (discussed in phase III Type I complex cognitive processing)

Figure 6.16. (Continued)

In Figure 6.16, there were no spoke or linear configurations formed in phase II. All the elements were chained which formed network configurations. However, the chaining was invalid and also showed contradiction in their links. For example, in Task 3, they constructed attribute links in explaining active transport and facilitated diffusion. This can be seen in the following excerpt.

L4 : …Glucose and amino acids are big (attribute) which move across the plasma membrane by facilitated diffusion (process).Ions are polar molecules (attribute) so they involved active transport (process).
R : Can glucose move through the plasma membrane via active transport?
L4 : No.
R : Why?
L4 : Because they need facilitated diffusion.
…
L2 : Because they are large molecules.
R : So all large molecules move across the plasma membrane by facilitated diffusion?
L2 : Yes.

(L2 & L4, Excerpt from classroom discussion, Task 3 Phase II)

Based on the above excerpt, L1, L2 and L4 generated the attribute links for different processes such as glucose and amino acids as they are large molecules which are transported by facilitated diffusion. However, contradiction of the links occurred for active transport and facilitated diffusion when they constructed different attribute links in Task 6 which was shown in Figure 6.16.

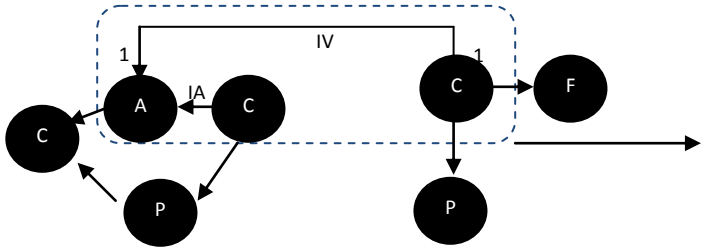
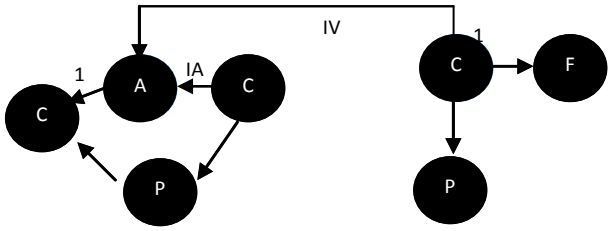
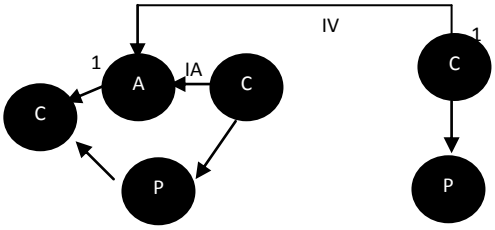
L1, L2 and L4, as can be seen in Figure 6.16, also seemed to struggle in generating related links for the application of the osmosis concept (such as food preservation) in the organisation element although they were able to chain the applications to the osmosis concept in the structural element. This can also be seen in another task when they had to reason out the consequence of a plant with excess fertilisers which were shown in the following excerpt.

R : What happens if a farmer pours a lot of fertiliser onto a plant?
L2 : Em… The plant will have hormone imbalance? I don't know.

(L2, Excerpt from classroom discussion, Task 7 Phase II)

Based on the above excerpt, L2 failed to chain the application (excess fertilisers in a plant) in the organisation element to the osmosis concept in the structural element. Thus, there was no chaining formed between the organisation and structural elements.

Hence in phase II, most of the time they managed to generate accurate links. Chaining between the elements was attempted by L1, L2 and L4, and several network configurations were formed; yet, the chaining was invalid. Therefore in phase II it can be said that they were at Type I complex cognitive processing.

Student	Type I Complex cognitive processing		Description
	ELEMENT		
	Structure	Organisation	
L1			1. Chaining between the elements 2.Invalid chaining between organisation and structural element
L2			
L4			

Description for invalid chaining between the structural and organisation elements

Hair keratin and enzymes are secondary structures (component) because they are coiled into α helix or β pleated sheet (attribute). Antibodies , haemoglobin and growth hormones are quaternary (component) because they have more than two polypeptides (attribute). L1's written task

Description for chaining across phases (Indicated in blue 1)

A nucleus has a nuclear membrane (component). The membrane is made up of phospholipids and transport protein (attribute). So, the organic components are lipids and protein (component). The mitochondrion also has a membrane (attribute) so the organic compounds that are involved are lipids and protein (component).Vacuoles store water (functional). Chloroplast is made up of starch (attribute) because it carries out photosynthesis (functional). The golgi apparatus transports protein, lipids and carbohydrate (functional). (Cell wall was left blank in the task) L2's written task

Description for chaining across phases (Indicated in blue 2)

*An enzyme is a protein (attribute). Ribosomes synthesise enzymes. The enzyme is then sent to RER and RER transports protein to the golgi apparatus. The golgi apparatus modifies, packages and transports enzymes out of the cell (process).*L4's written task

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase I and II

Figure 6.17. L1, L2 and L4's Type I complex cognitive processing in phase III

In Figure 6.17, there are no spoke or linear configurations formed in phase III. All the elements are chained to form network configurations between the elements within a phase as well as across the phases. However, some of the chaining were invalid. For example, the attribute links for the different types of protein structure were accurately chained in the structural element in phase III; yet, the protein structure for enzymes, antibodies and growth hormones were mismatched with the diagram given in the task given for in the organisation element. For example, enzymes, antibodies and growth hormones showed the folding structure of helix or β pleated sheet into three dimensional shapes in the diagram which belonged to the tertiary group. Nonetheless, L1 perceived them as secondary or quaternary. The mismatch also occurred with L2 and L4.

Nevertheless, L1, L2 and L4 showed some valid chaining across the phases. For example, in describing the production of enzymes, he chained enzymes (entity) to the organic compound (structural component in phase III) which is a protein, and explained the enzyme synthesis process by chaining to the structural and functional links in phase I. Apart from that, in phase I, L1, L2 and L4 were weak in chaining the property of the organelles. As they progressed to phase III, they were able to describe the property of mitochondrion as consisting of a membrane. As a result, they were able to further describe the organic compounds that made up the mitochondria which are lipids as the membrane is made up of phospholipids bilayer. However some organelles were linked to its function link instead of the attribute link of the organelle. For example, the golgi apparatus transports proteins, carbohydrate and lipids (functional link) and therefore the organic compounds that make up the golgi apparatus are carbohydrates, proteins and lipids.

Similar to phase II, L1, L2 and L4 seemed to encounter problems with the tasks which were related to the application of cell division in the organisation element of phase

IV. As a result, they were unable to construct the chaining between the genetics with other elements. The configuration in phase IV is shown in Figure 6.18.

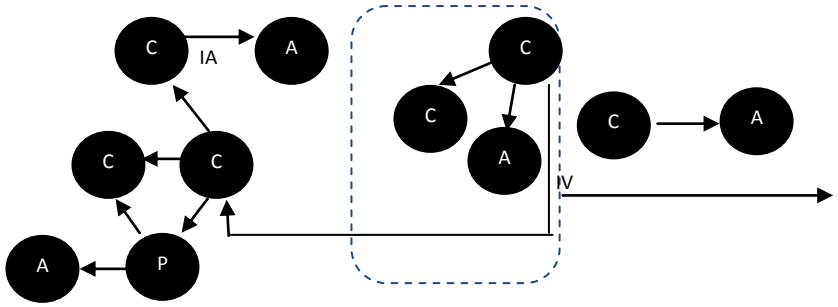
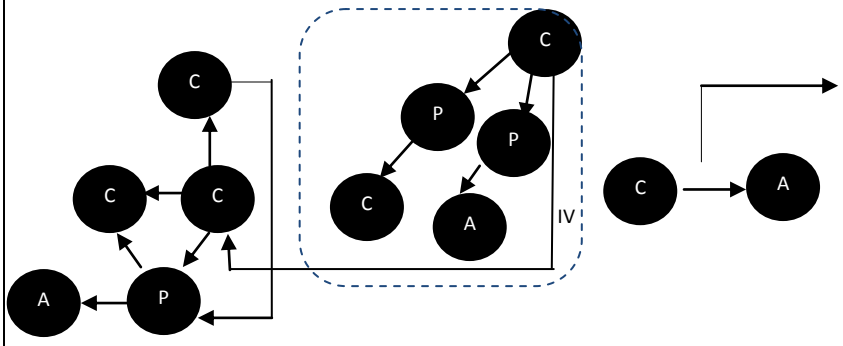
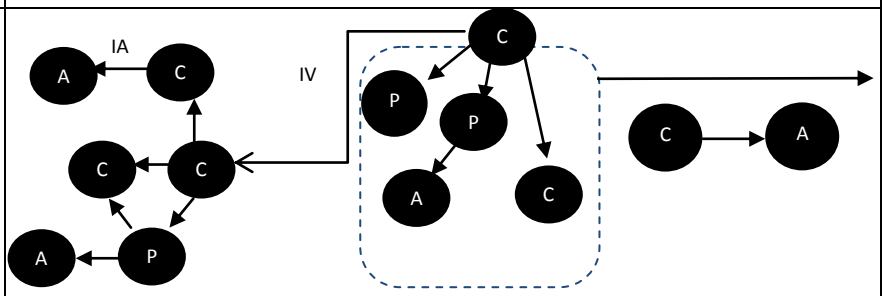
Student	Type I Complex cognitive processing			Description
	ELEMENT			
	Structure	Organisation	Genetics	
L1				1. Invalid Chaining
L2				2. Invalid chaining between genetics and structural elements
L4				3. Invalid chaining between structural and organisation elements

Figure 6.18. L1, L2 and L4's Type I complex cognitive processing in phase IV

Description for invalid chaining between the structural and organisation elements
Cancer is caused by taking a lot of bad things such as smoking, chemical substances and drugs (component). Non-disjunction occurs when the chromosome is imbalanced (attribute). L2's written task *Cancer is formed from malignant tumours when something goes wrong*. L1's written task
Description for genetics element
The genetic are different for different types of cells because they are different types of cells. Sperm and ovum undergo meiosis where crossing over occurs. So the genetics are also different. L4's written task

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

Figure 6.18. (Continued)

In Figure 6.18, there were no spoke or linear configurations formed in phase IV. All the elements which were chained which formed more than two network configurations between the elements. However, the chaining was invalid.

As can be seen in Figure 6.18, although L1, L2 and L4 constructed network configurations, yet, some of the links in the organisation element were not chained to the structural element. For example, L2 described that cancer was caused by smoking. However, how smoking causes cancer could not be answered by L2 during the classroom discussion. This was supported by the excerpt below.

L1 : Cancer is formed from malignant tumours.
R : How is a malignant tumour formed?
L1 : When … em… something goes wrong.
R : What goes wrong?
L1 : (Silence)
…
L2 : Cancer is formed when a person smokes a lot.
R : How can smoking cause cancer?
L2 : Because a cigarette contains a lot of harmful substances such as nicotine
R : How can harmful substances cause cancer?
L2 : Em…I don't know.

(Excerpt from classroom discussion)

Based on the excerpt above, L1 was unable to generate accurate links for the formation of a malignant tumour by just stating ‘something goes wrong’. Although L2 was able to reason that cigarette smoke contains harmful substances that cause cancer, he was unable to chain how these harmful substances could lead to the disruption of the mitotic process in the structural element.

A similar situation was also found as they proceeded to the genetics element in phase IV. After learning cell division in phase IV, L1, L2 and L4 still believed that the genetics of each cell will be different. L1 and L4 were only able to chain the meiosis process in the structural element to the genetics element in their reasoning. Although L2’s mechanistic reasoning revealed chaining to the mitotic and meiosis process, his mechanistic reasoning revealed an invalid chaining. For example, L2 explained that mitosis takes place only among the same types of cells.

Hence in phase IV, L1, L2 and L4 for most of the time managed to generate accurate links. Chaining between the elements was attempted by them, and several network configurations were formed; yet, the chaining was invalid. The chaining was invalid especially between the structural and organisation elements.

Table 6.10

L3's Overall Mechanistic Reasoning for the Theory of Cell

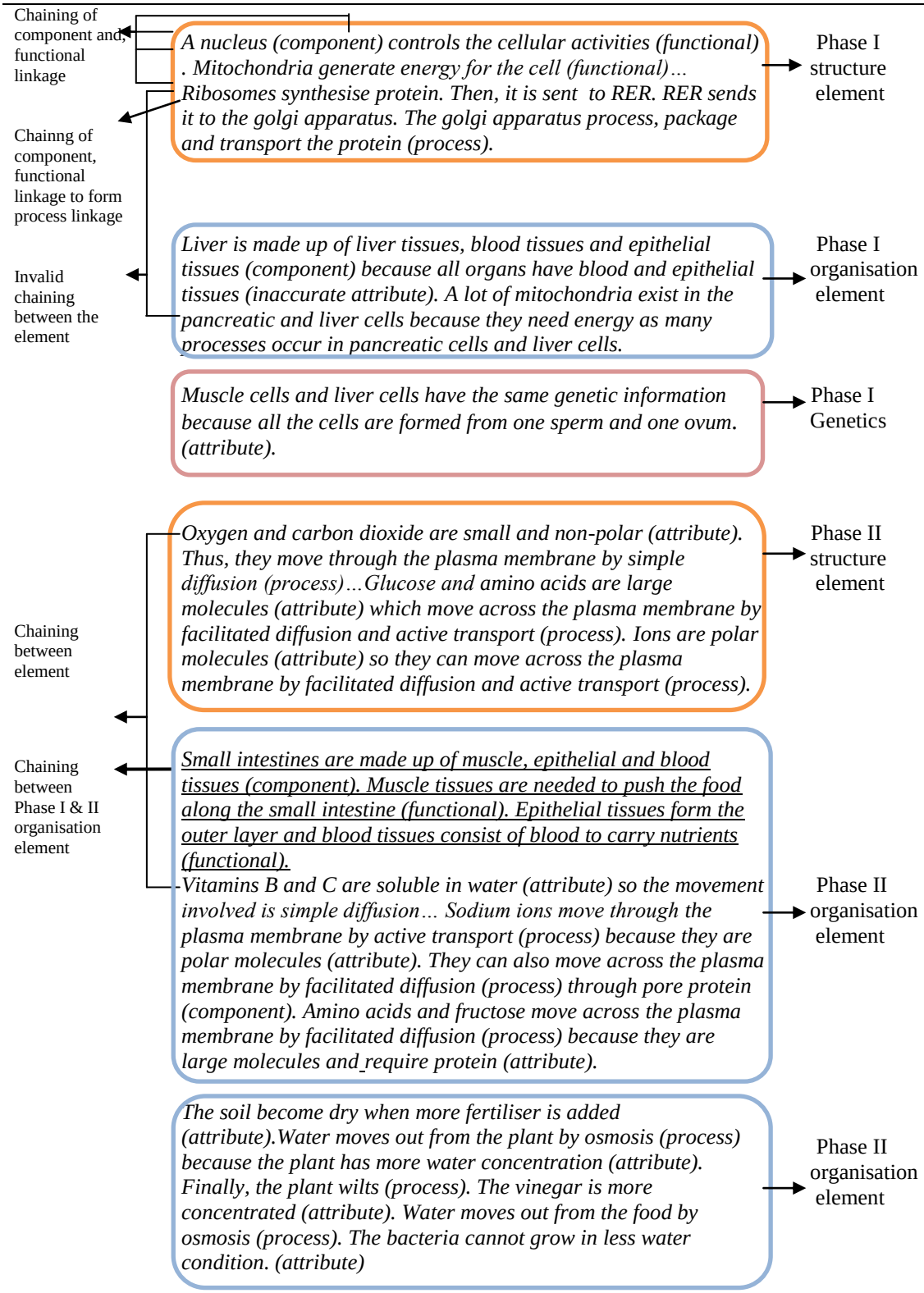


Table 6.10 (Continued)

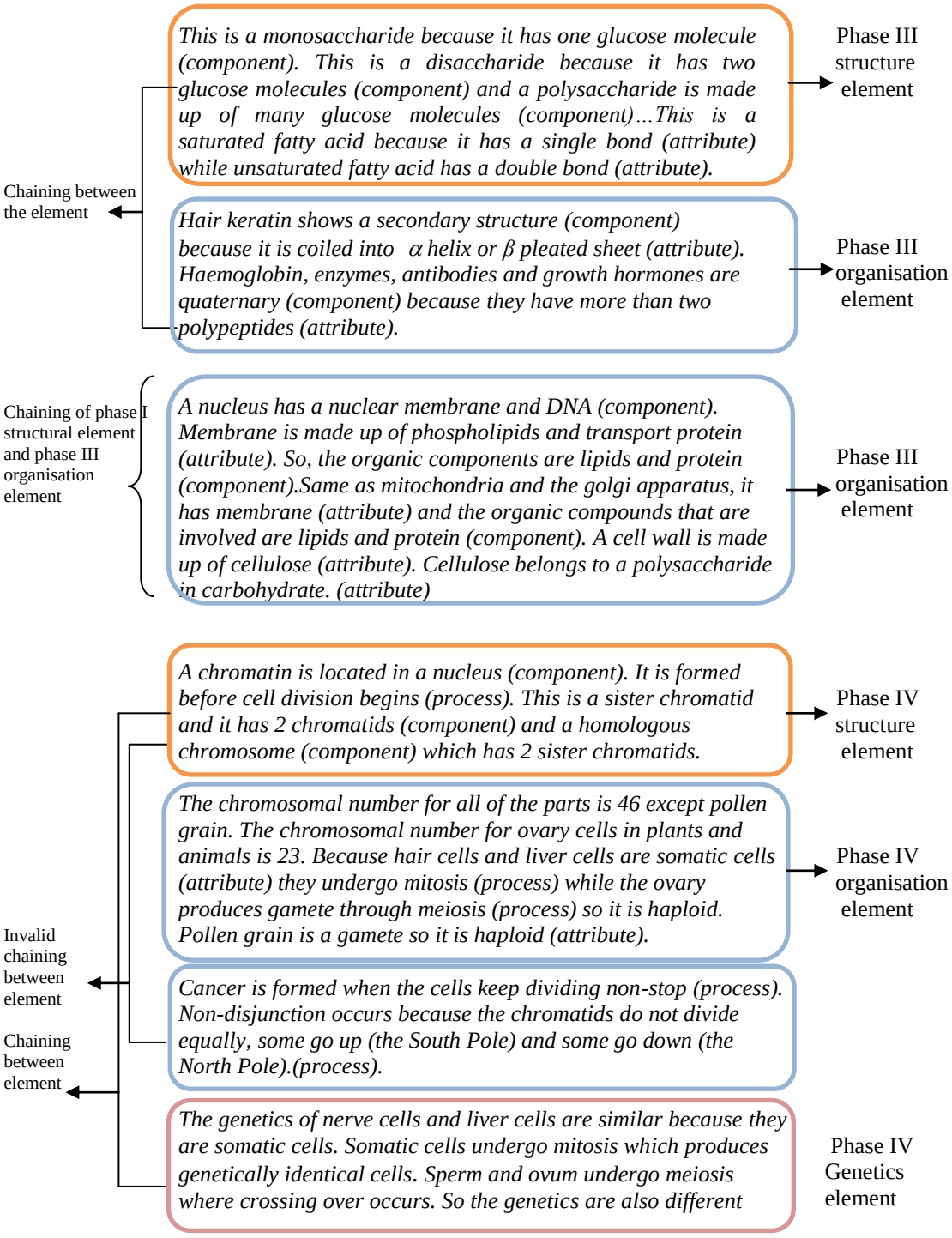


Table 6.11

L5's Overall Mechanistic Reasoning for the Theory of Cell

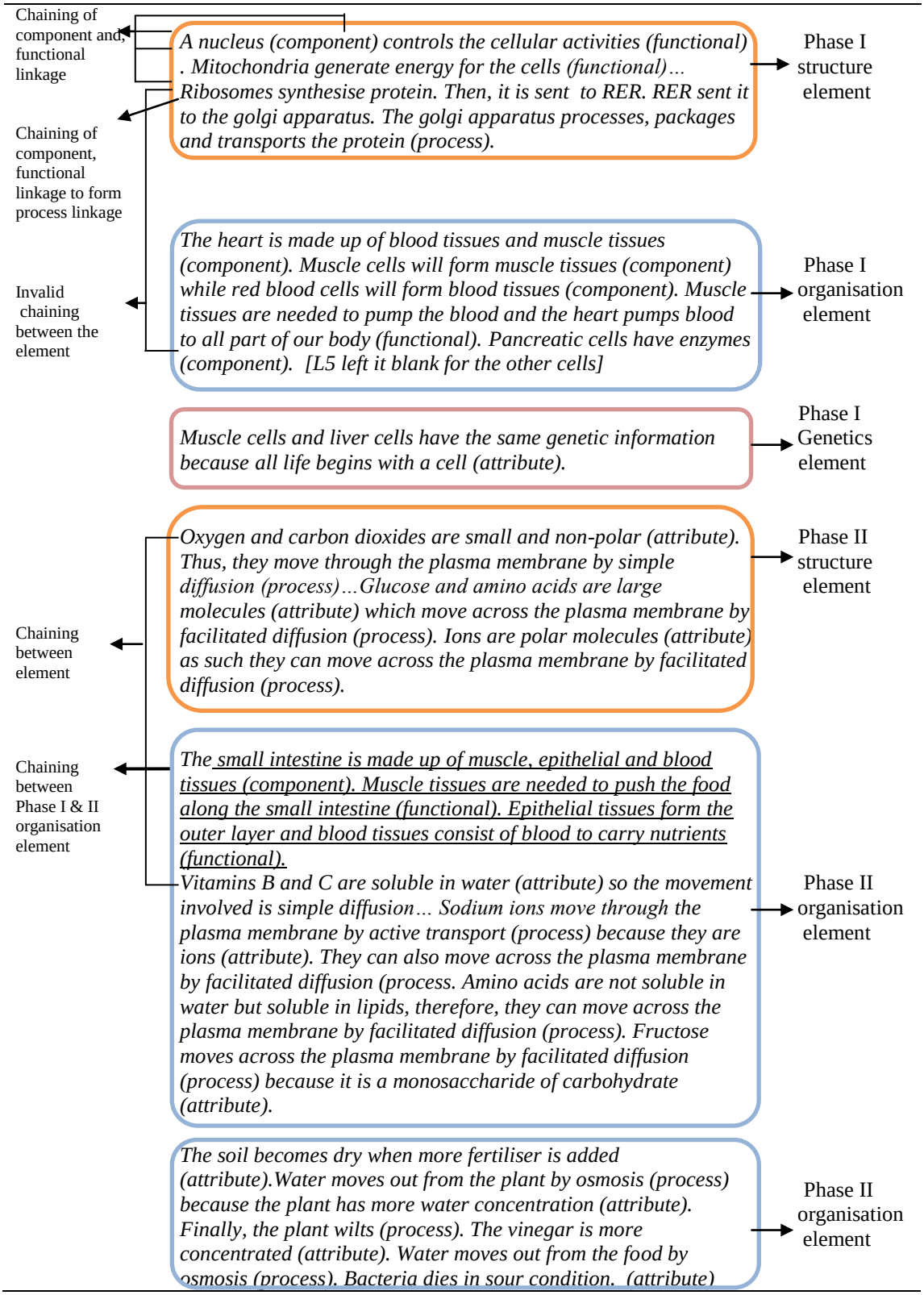
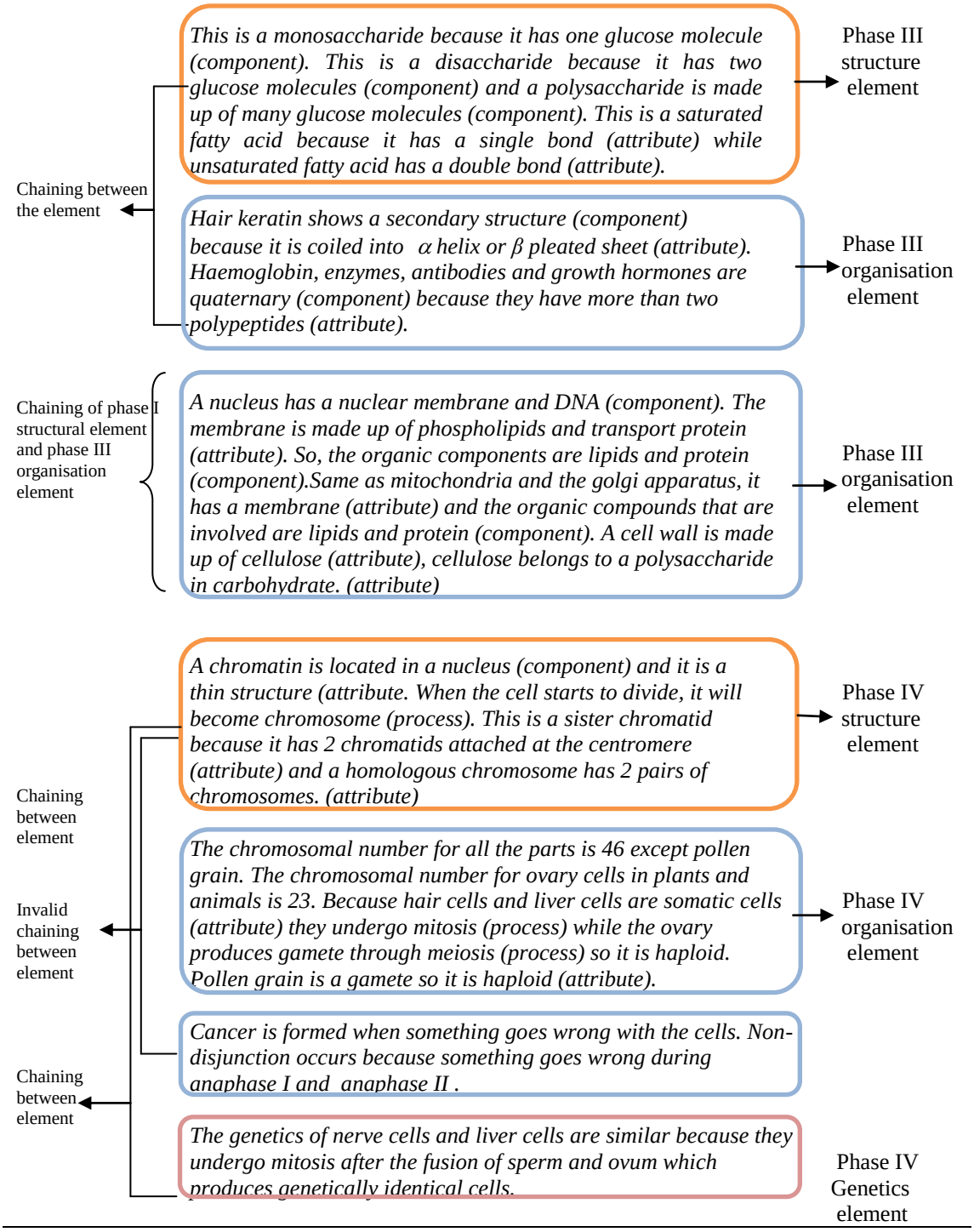


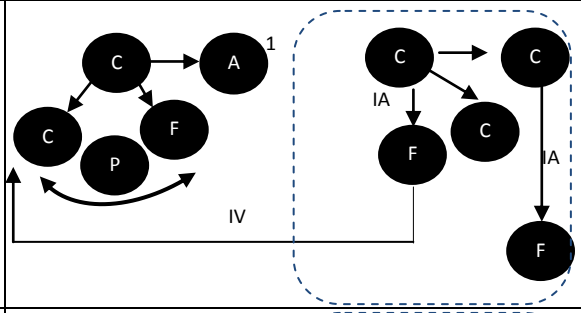
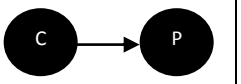
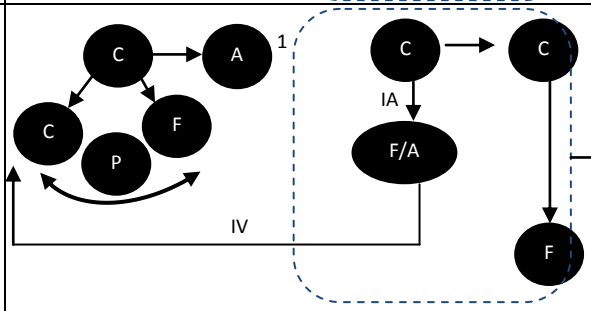
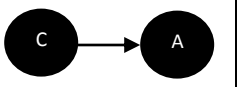
Table 6.11 (Continued)



Tables 6.10 and 6.11 show L3 and L5's overall mechanistic reasoning for the Theory of Cell acquired from phase I to phase IV. The mechanistic reasoning acquired by L3 and L5 comprises the component, attribute, functional and process links for the Theory of Cell. How L3 and L5 have also managed to chain these links between the elements within a phase as well as across the phases is indicated in the table. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by phase and it was found that in phase I , L3 and L5 demonstrated Type II simple cognitive processing. In phases II, L3 and L5 demonstrated Type II complex cognitive processing. In phase III and IV, L3 and L5 demonstrated Type I complex cognitive processing. These will now be discussed.

Type II Simple Cognitive Processing

In phase I (Figure 6.19), the component, attribute and functional links formed within each element could be classified as having spoke and network configurations. There were two network configurations formed which were within the structural element as well as between the structural and organisation elements. The majority of the links are accurate; yet, the chaining that formed network configurations were invalid. There is no chaining between the structural or organisation to genetics elements. Thus, L3 and L5's reasoning is classified as Type II simple cognitive processing. This is shown in Figure 6.19.

<table>
<tr><th rowspan="3">Student</th><td colspan="3">Type II Simple cognitive processing</td><th rowspan="3">Description</th></tr>
<tr><td colspan="3">ELEMENT</td></tr>
<tr><td>Structure</td><td>Organisation</td><td>Genetics</td></tr>
<tr><td>L3</td><td> 
</td><td> 
</td><td>1. No chaining between genetics to other elements</td></tr>
<tr><td>L5</td><td> 
</td><td> 
</td><td>2. Invalid chaining between organisation and structural elements</td></tr>
<tr><td colspan="4"><u>Description for invalid chaining between the structural and organisation elements</u>

Pancreatic cells have enzymes (component). [L5 left it blank for the other cells].

Plenty of mitochondria exist in pancreatic and liver cells because they need energy as many processes occur in the pancreatic cells and liver cells.
(L3’s mechanistic reasoning)</td></tr>
<tr><td colspan="4"><u>Description for no chaining between genetics to other elements</u>

Muscle cells and liver cells have the same genetic information because all the cells were formed from one sperm and one ovum. (attribute).
(L3’s mechanistic reasoning)

Muscle cells and liver cells have the same genetic information because all life begins with a cell (attribute).(L5’s mechanistic reasoning)</td></tr>
</table>

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III

Figure 6.19. L3 and L5’s Type II simple cognitive processing in phase I

Based on Figure 6.19, they encountered few problems in identifying the different types of links such as attribute, functional and process links in the structural element. For example, L3 and L5 were able to describe the cellular processes such as protein and lipid

synthesis by constructing process links as shown in Figure 6.19. As they proceeded to the organisation element, L3 and L5 were able to demonstrate the different types of tissues (component link) that made up an organ However, the reason given by L3 related to the function of the cells indicated lack of accurate links which was revealed in his written task as follows:

L3 : Liver is made up of liver tissues, blood tissues and epithelial tissues because all organs have blood and epithelial tissues.

(L3's written task)

As shown in the excerpt above, L3 reasoned that organs are made up of blood and epithelial tissues because all organs are made up of those tissues. This revealed a lack of links generated in his reasoning.

In contrast, L5 was able to construct the functional linkage precisely which was revealed in his written task as follows:

L5 : The heart is made up of blood tissues and muscle tissues (component). Muscle cells will form muscles tissues while red blood cells will form blood tissues . Muscle tissues are needed to pump the blood (functional) and the heart pumps blood to all parts of our body (functional).

(L5's written task)

The chaining performed in Phase I was largely invalid as shown in Figure 6.20. The reason why the organisation element was weakly chained to the structural element is probably due to the inaccurate attribute or functional links generated in the organisation element. For example, L3 reasoned that many processes occurred in the liver and pancreatic cells, therefore mitochondria are found abundantly. L3 and L5 were unable to identify the specific functional link of the pancreatic and liver cells; as a result, the chaining between the structural and organisation elements was invalid.

As for the genetics element, L5 generated a linear configuration by generating attribute links. Although both of them were able to identify that the genetics of different types of cell will be the same, they failed to chain to the structural and organisation elements.

Type I Complex Cognitive Processing

In phase III, the component, attribute and functional links formed within each element could be classified as network configurations. There were no spoke or linear configurations formed. Network configurations were constructed between the structural and organisation elements and across phases. The majority of the links were accurate; yet, the chaining that formed network configurations was invalid. Thus, L3 and L5's reasoning is classified as Type I complex cognitive processing. This is shown in Figure 6.20.

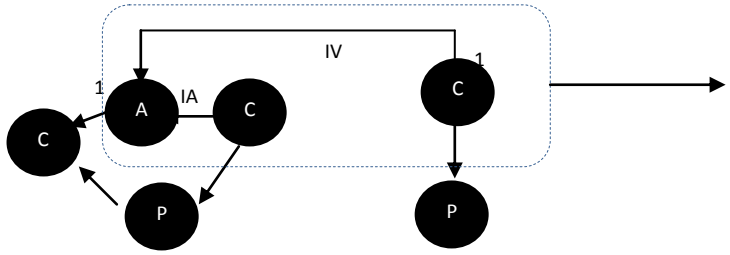
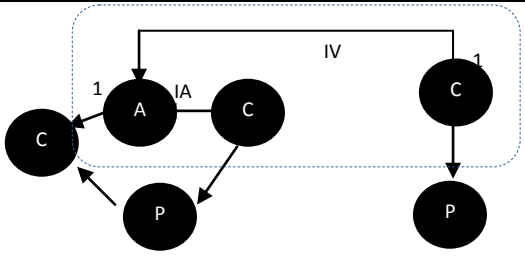
Student	Type I complex cognitive processing		**Description**
	ELEMENT		
	Structure	**Organisation**	
L3			1. Invalid chaining between organisation and structural elements
L5			

Figure 6.20. L3 and L5's Type II simple cognitive processing in phase III

Description for invalid chaining between the structural and organisation elements *Hair keratin shows a secondary structure (component) because it is coiled into α- helix or β pleated sheet (attribute). Haemoglobin, enzymes, antibodies and growth hormones are quaternary (component) because they have more than two polypeptides (attribute).* (L3& L5's mechanistic reasoning)
Description for chaining across phases *A nucleus has a nuclear membrane and DNA (component, phase I). The membrane is made up of phospholipids and transport protein (attribute, phase II). So, the organic components are lipids and protein (component, phase III).Same as mitochondria and the golgi apparatus, it has a membrane (attribute, phase I) and the organic compounds that are involved are lipids and protein (component, phase III). A cell wall is made up of cellulose (attribute, phase I), cellulose belongs to a polysaccharide in carbohydrate. (attribute, phase III)* (L3& L5's mechanistic reasoning)

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase I

Figure 6.20. (Continued)

Based on Figure 6.20, many of the links within each element were accurate. However, probably due to lack of links generated, the chaining in phase III only contributed to a few network configurations. In addition, the chaining was invalid.

In phase III (based on Figure 6.20), the chaining was invalid especially between the organisation and structural elements. For example in phase III, they were able to develop accurate attribute or component links in the structural element (for carbohydrates, proteins and lipids); yet, both mechanistic reasoning revealed invalid chaining of the property (attribute link) of the proteins in the structural element to the protein structure for enzymes, antibodies and growth hormones in the organisation element. For example, enzymes, antibodies and growth hormones showed the folding structure of helix or β pleated sheet into three dimensional shapes in the diagram which belonged to the tertiary group. Nonetheless, L3 perceived them as quaternary. This was later confirmed in an interview that L3 was unsure of the shape of the tertiary structure which was revealed in the excerpt below.

R : *Why do you categorise this as quaternary instead of tertiary?*
L3 : *Em…because it has more than 2 polypeptides.*
R : *What about the tertiary structure?*
L3 : *The tertiary structure is coiled into three dimensional shapes.*
R : *So is this not tertiary?*
L3 : *I don't know how the three dimensional shape looks like.*

(Excerpt from interview)

Nevertheless, L3 and L5 were able to demonstrate some valid chaining across the phases. They were able to chain the organic compound of an organelle in the organisation element of phase III to the attribute link in phase I and the component link in phase II. This is shown in the written tasks by L3 and L5 in Figure 6.20.

In phase IV, L3 and L5 demonstrated more accurate links and attempted more instances of chaining between elements within a phase to form several network configurations. However, several links and chains were inaccurate. This will be discussed in more detail.

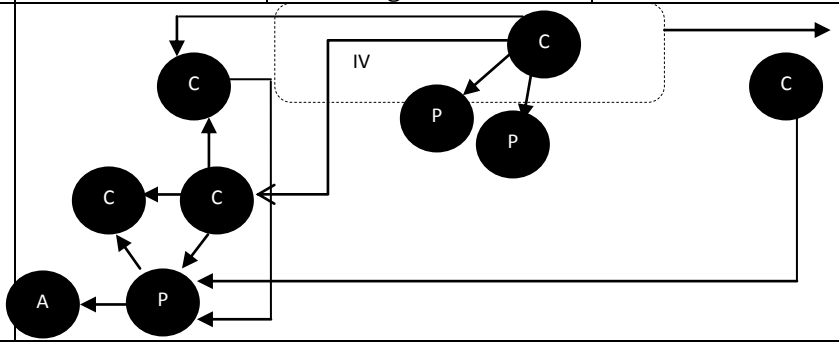
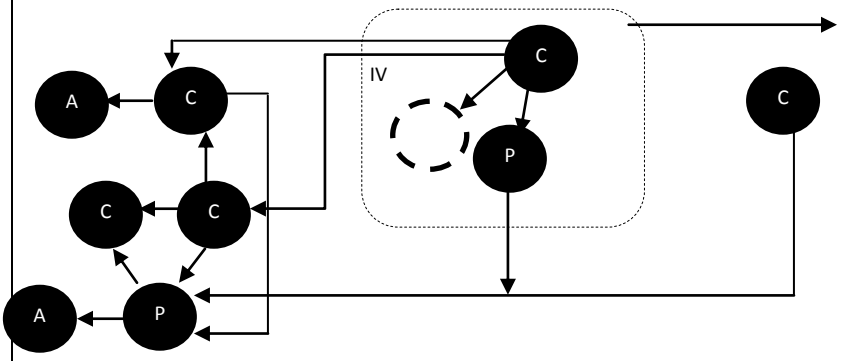
Student	Type I Complex cognitive processing			**Description**
	ELEMENT			
	Structure	**Organisation**	**Genetics**	
L3				1. Invalid chaining of component link in organisation element to structural element

Figure 6.21. L3 and L5's Type I complex cognitive processing in phase IV

L5		2. Lack of chaining between organisation and structural elements
Invalid chaining of the component link in the organisation element to the structural element *The chromosomal number for hair and liver cells is 46 while pollen grain, ovary cells in plants and animals and cells in fallopian tube have a chromosomal number of 23.Because hair cells and liver cells are somatic cells, they undergo mitosis while the rest are reproductive cells.* *(L5's mechanistic reasoning)*		
Description for lack of chaining between the structural and organisation elements *Cancer is formed when something goes wrong with the cells. Non-disjunction occurs because something goes wrong during anaphase I and anaphase II.* *(L5's mechanistic reasoning)* *Cancer cells are formed when the cells keep dividing non-stop. Non-disjunction occurs because the chromatids do not divide equally.* *(L3's mechanistic reasoning)*		
Chaining between the genetics and structural elements *The genetics of nerve cells and liver cells are similar because they are somatic cells. Somatic cells undergo mitosis which produces genetically identical cells. Sperm and ovum undergo meiosis where crossing over occurs. So the genetics are also different.* *(L3& L5's mechanistic reasoning)*		

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

Figure 6.21. (Continued)

In Figure 6.21, there were no spoke or linear configurations formed in phase IV. All the elements in phase IV were chained to form network configurations. However, some of the chaining was invalid.

In phase IV, most of the links demonstrated were accurate; however, the chaining was invalid especially between the organisation and structural elements. For example L3 and L5 had no difficulty chaining the process link (meiosis and mitosis) and the component link that involved (gametes and somatic cells) in the structural element which was shown in

Figure 6.21, but they demonstrated invalid chaining between the chromosomal number of gametes and cells in the reproductive organs in the organisation element to the process link (mitosis and meiosis) in the structural element. L3 and L5 assumed that the cells in the fallopian tube consist of half the number of chromosomes as they are reproductive cells (organisation element) and reproductive cells undergo meiosis (structural element). The chaining is invalid because the cells in the fallopian tube are not reproductive cells and they undergo the mitosis process instead of meiosis.

Another example of invalid chaining shown in their mechanistic reasoning in the organisation element was the application of cell division. L3 described the formation of cancer as being caused by the cells dividing repeatedly but he could not explain how the cells divided repeatedly. Both L3 and L5 thought that something must have been wrong with the cells which they could not explicitly explain. Thus, it showed an invalid chaining between the organisation and structural elements.

Likewise, L3 and L5 were unable to construct valid chaining to the structural element for the non-disjunction process. As a result, they ended up giving similar process links when the teacher tried to prompt the students. For example, L3 explained the reason chromatids do not divide equally as some that go to the North Pole and some go to the South Pole. L3 failed to chain to the meiosis process in the structural element in explaining how this process takes place. This is shown in the following excerpt.

R : Why do the cells keep dividing?
L5 : Because...something goes wrong with the cell?
R : What goes wrong?
L5 : Em… I don't know.
…
R : Why does this person have an abnormal chromosomal number?
L3 : Because the chromatids do not divide equally.
R : Why are the chromatids do not dividing equally?

L3 : Some go up (the South Pole) and some go down (the North Pole).
R : How does this happen?
L3 : Hm…I don't know.

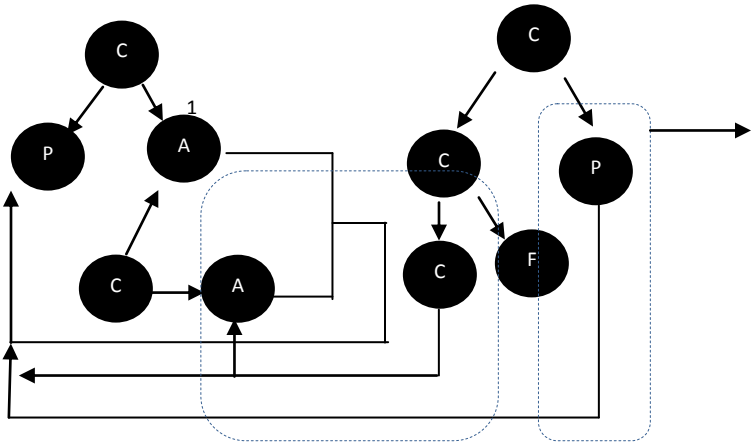
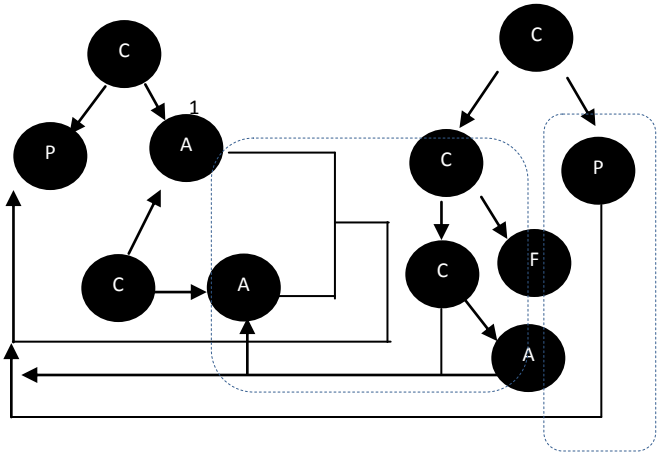
(L3 & L5, Excerpt from classroom discussion, Task 6 Phase IV)

On the other hand, both L3 and L5 were able to chain the attribute link in the structural element to the genetics element which is illustrated in Figure 6.21. Although L3 and L5 recognised the chaining between the structural and the genetics elements in phase IV, they failed to recognise the chaining of the cell specialisation process in phase I in reasoning the production of different types of cells. Therefore, there was no chaining across the phases demonstrated in phase IV.

Hence in phase IV, L3 and L5 for most of the time managed to generate accurate links. The chaining between the elements was attempted by L3 and L5, and several network configurations were formed; yet, the chaining is invalid. Therefore in phase IV it can be said that L3 and L5 were at Type I complex cognitive processing.

Type II Complex Cognitive Processing

The only type II complex cognitive processing demonstrated by L3 and L5 were the movement of substances across the plasma membrane (phase II). Both of them demonstrated more accurate links as well as valid chaining between the elements within a phase to form more than two network configurations. This is shown in Figure 6.22 and will be discussed in more detail.

Student	Type II Complex cognitive processing		Description
	ELEMENT		
	Structure	**Organisation**	
L3			1. Valid chaining between organisation and structural elements
L5			

Description for chaining between the structural and organisation elements

The soil becomes dry when more fertiliser is added (attribute).Water moves out from the plant by osmosis (process) because the plant has more water concentration (attribute). Finally, the plant wilts (process). The vinegar is more concentrated (attribute). Water moves out from the food by osmosis (process). Bacteria dies in a sour condition. (attribute)

(L5's mechanistic reasoning)

The vinegar is more concentrated (attribute). Water moves out from the food by osmosis. The bacteria cannot grow in less water condition. (process)

(L3's written task)

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III (being discussed in phase III Type II simple cognitive processing)

Figure 6.22. L3 and L5's Type II complex cognitive processing in phase II

In Figure 6.22, there are no spoke or linear configurations formed in phase II. All the elements were chained which formed network configurations. Furthermore, the chaining between the elements was valid. They were able to construct accurate links in their reasoning especially the application in the organisation element such as preservation of food and consequences of excess fertiliser in plants.

Similarly, L3 and L5 also demonstrated valid chaining of the substances (component link) given in the organisation element to the attribute and process links in the structural element. This is shown below in the written task by L3.

> *Sodium ions move through the plasma membrane by active transport (process) because they are polar molecules (attribute). They can also move across the plasma membrane by facilitated diffusion (process) through pore protein (component). Amino acids and fructose (component) move across the plasma membrane by facilitated diffusion (process) because they are large molecules and require protein (attribute).*
>
> *(L3's written task)*

Based on the written task above, the attribute links (big/ small, polar/ non-polar) were accurately generated for different substances (sodium ions, amino acids and fructose). Thus, the process links generated were also accurate.

Hence in phase II, L3 and L5 for most of the time managed to generate accurate links. In addition, chaining between the elements demonstrated by L3 and L5 were accurate, consequently more than two network configurations were formed. Therefore in phase II it can be said that L3 and L5 were at Type II complex cognitive processing.

Table 6.12

L6's Overall Mechanistic Reasoning for the Theory of Cell

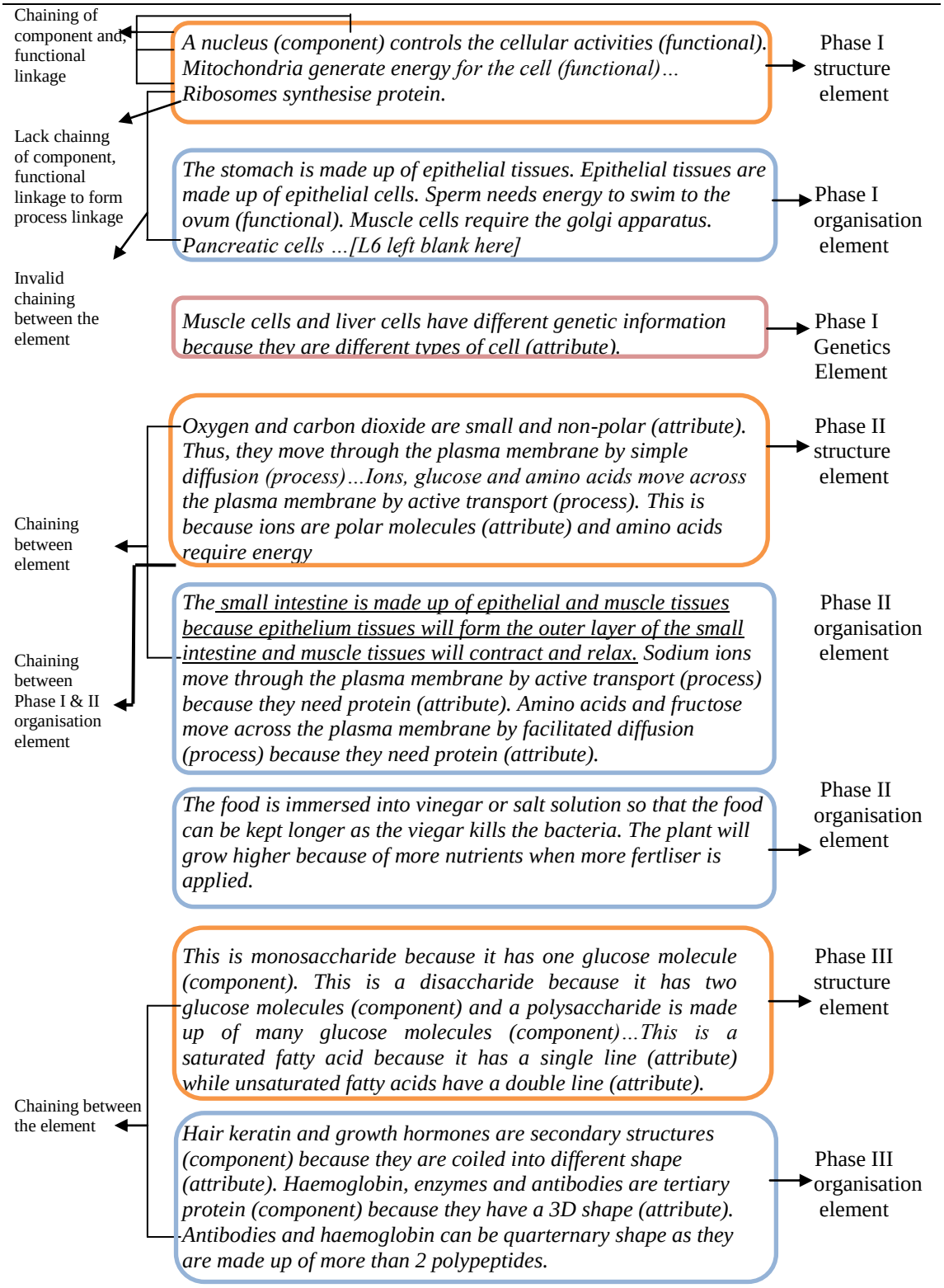


Table 6.12 (Continued)

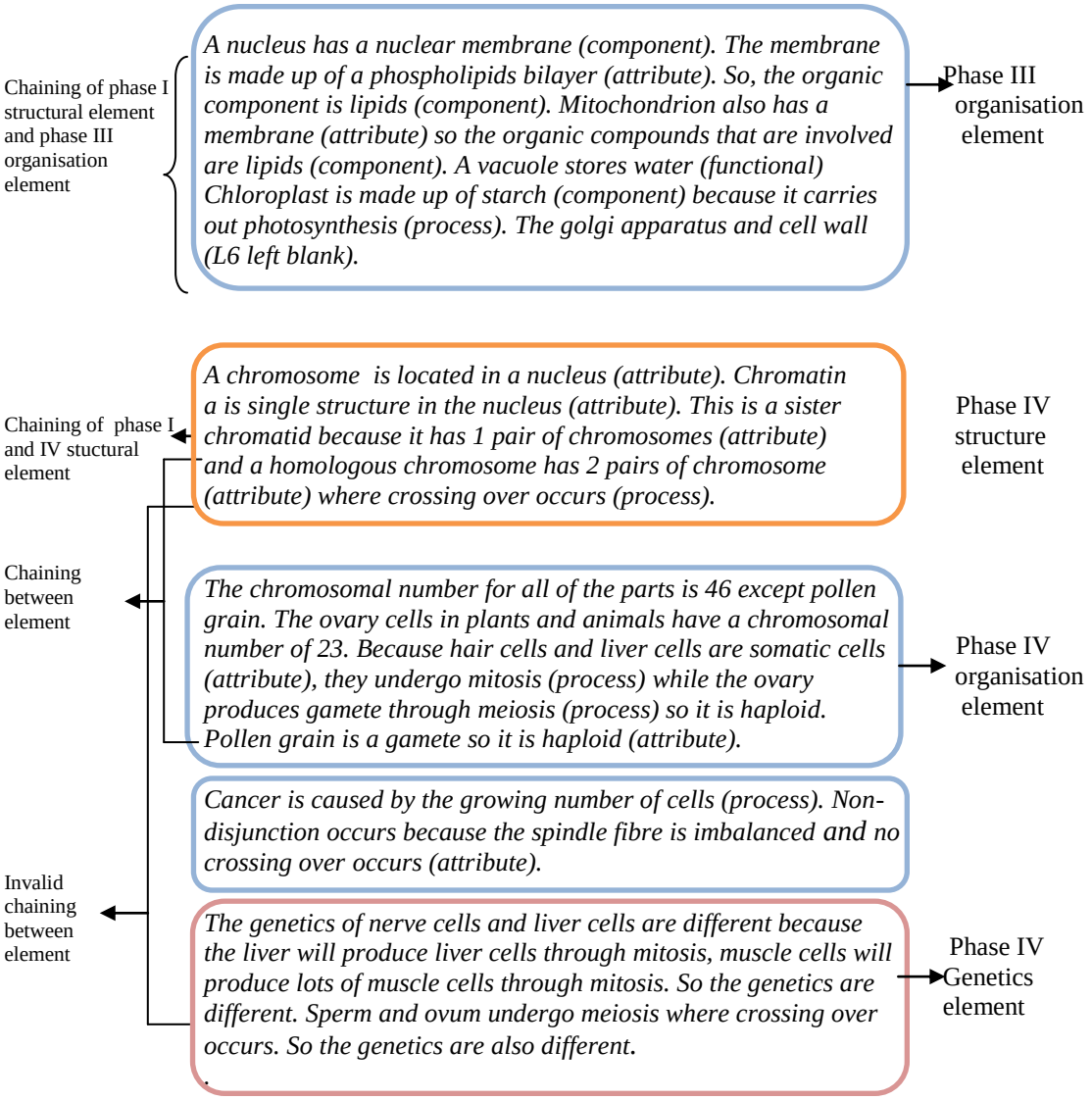
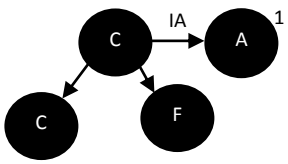
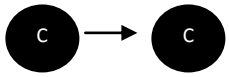
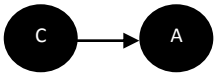


Table 6.12 shows L6's overall mechanistic reasoning for the Theory of Cell acquired through phase I to phase IV. The mechanistic reasoning acquired by L6 comprises the component, attribute, functional and process links for the Theory of Cell in all the phases as also shown in Table 6.12. How L6 has also managed to chain these links between the elements within a phase as well as across phases is indicated in the table. The cognitive processing involved in attaining this overall mechanistic reasoning was identified phase by

phase and it was found that in phase I, L6 demonstrated Type I simple cognitive processing. In phases II, III and IV, he demonstrated Type I complex cognitive processing. The cognitive processing will now be discussed.

Type I Simple Cognitive Processing

In phase I, the component, attribute and functional links formed within each element could be classified as having spoke and linear configurations. There is no network configuration formed even within one element. There is no chaining between the elements as well. Thus, L6's reasoning is classified as Type I simple cognitive processing. This is shown in Figure 6.23.

<table>
<tr><td rowspan="3">TYPE</td><td colspan="3">Type I Simple cognitive processing</td></tr>
<tr><td colspan="3">ELEMENT</td></tr>
<tr><td>Structure</td><td>Organisation</td><td>Genetics</td></tr>
<tr><td>Phase I</td><td> 
</td><td> 
</td><td> 
</td></tr>
<tr><td colspan="4">No chaining between the elements</td></tr>
<tr><td colspan="4">Description for the structural element
A nucleus (component) controls the cellular activities (functional). Mitochondria generate energy for the cell (functional)… Ribosomes synthesise protein.</td></tr>
<tr><td colspan="4">Description for no chaining between the structural and organisation elements
The stomach is made up of epithelial tissues. Epithelial tissues are made up of epithelial cells.

Muscle cells require the golgi apparatus. Pancreatic cells …[L6 left blank here]</td></tr>
<tr><td colspan="4">Description for the genetics element
Muscle cells and liver cells have different genetic information because they are different types of cell (attribute).</td></tr>
</table>

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III (will be discussed in phase III Type II simple cognitive processing

Figure 6.23. L6 Type I simple cognitive processing in phase I

Based on Figure 6.23, L6 showed a lack of attribute link of certain organelles in the structural element. This was also verified during the classroom discussion even though prompting was given by the researcher.

R : Can you give me the characteristic of the golgi apparatus?
L6 : Em…(silence)
R : What about mitochondria?
L6 : Em ...I don't know.
R : What about the nucleus?
L6 : Em ...I don't know.

(Excerpt from classroom discussion)

Based on the excerpt above, L6 was unable to generate the attribute link for mitochondrion, the golgi apparatus and the nucleus. Furthermore, only component links were identified in the organisation element in describing different organelles. For example, only one type of cell was identified in an organ and the function link of the different types of cells was also absent. As a result, there was no chaining to the structural component.

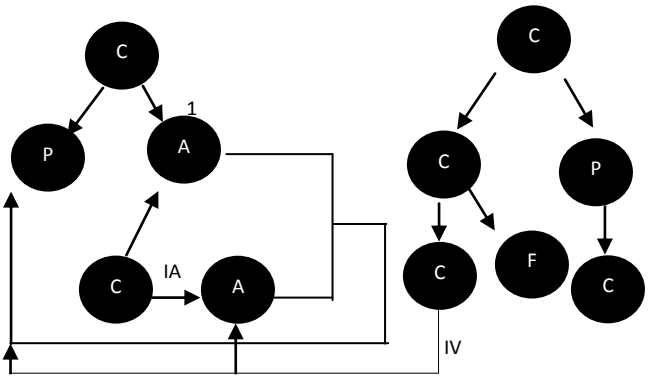
As for the genetics element, L6 reasoned that different types of cell have different genetic information since they are different. Again, this indicated lack of links generated and this might be the reason why no chaining was constructed to other elements.

Generally, L6's mechanistic reasoning in phase I revealed insufficient links generated. Consequently, no chaining was generated by L6 and 'I don't know' was the reason frequently answered by L6 whenever prompting was given to him. Hence, it can be said that L6 was at Type I simple cognitive processing.

Type I Complex Cognitive Processing

In phase II, III and IV, the component, attribute and functional links formed could be classified as having network configurations. The majority of the links were accurate and

network configurations were generated. Yet, the chaining that formed the network configurations was invalid. Thus, L6's reasoning is classified as Type I complex cognitive processing. This is shown in Figure 6.24.

<table>
<tr><td rowspan="2">TYPE</td><td colspan="2">Type I Complex cognitive processing</td></tr>
<tr><td colspan="2">ELEMENT</td></tr>
<tr><td></td><td>Structure</td><td>Organisation</td></tr>
<tr><td>Phase II</td><td colspan="2"> 
</td></tr>
<tr><td colspan="3">Invalid chaining between the structural and the organisation element</td></tr>
<tr><td colspan="3">Description for invalid and lack of chaining between the structural and organisation elements

Sodium ions (component) move through the plasma membrane by facilitated diffusion (process) because they need protein (attribute). Amino acids and fructose (component) move across the plasma membrane by facilitated diffusion (process) because they need protein (attribute)…</td></tr>
<tr><td colspan="3">Description for chaining across the phases

The small intestine is made up of epithelial and muscle tissues (component) because epithelium tissues form the outer layer and muscle tissues will contract and relax (functional).</td></tr>
<tr><td colspan="3">Description for the lack of chaining between the structural and organisation elements

Food is immersed into vinegar or salt solution because it can keep longer.</td></tr>
</table>

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase III (being discussed in phase III Type II simple cognitive processing

Figure 6.24. L6 Type I complex cognitive processing in phase II

Based on Figure 6.24, L6 generated more links in phase II and phase IV as compared to phase III (which will be discussed later). However, the attribute link generated

in the structural element was inaccurate in phase II. L6 stated the attribute link for ions as polar molecules while the attribute link for amino acids is that 'they require energy'. While in the organisation element, he generated different attribute links for similar substances although the task was different. He differentiated different types of transport based on the need to transport protein (attribute link) which is indicated in Figure 6.24.

Although L6 indicated that he attempted to construct chaining between the structural and organisation elements, he only managed to construct one invalid chaining between the elements which is described in Figure 6.24. The failure to chain between the organisation and structural elements was probably because L6 was unable to chain the osmosis process in describing the applications of osmosis in the organisation element even though he was able state the consequences of both situations. The following excerpt indicated L6's mechanistic reasoning in food preservation and excessive fertilisers in the plants.

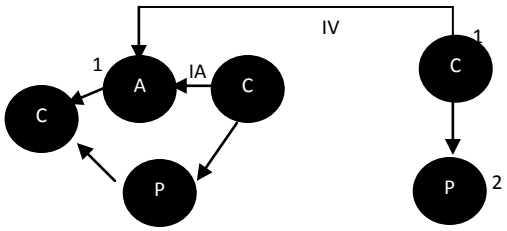
R : Why is the food immersed into vinegar or salt solution?
L6 : To keep longer.
R : Why can the food be kept longer?
L6 : because the condition will kill the bacteria.
R : What happens if a farmer pours a lot of fertiliser on a plant?
L6 : Em… The plant will grow
R : Why?
L6 : Because…because… more nutrient.

(Excerpt from classroom discussion)

Based on the excerpt above, L6 gave the consequences such as the food can be kept longer or the plant will grow for the applications (food immersed in vinegar and excessive fertilisers on a plant) instead of reasoning mechanically the consequences of both applications.

In phase III, the component, attribute and functional links formed within each element could be classified as network configurations. There are no spoke or linear

configurations and, network configurations formed which is between the structural and organisation elements and across the phases. The majority of links are accurate; yet, the chaining that formed the network configurations was invalid. Thus, L6's reasoning is classified as Type I complex cognitive processing. This is shown in Figure 6.25.

<table>
<tr><td rowspan="3">TYPE</td><td colspan="2">Type I Complex cognitive processing</td></tr>
<tr><td colspan="2">ELEMENT</td></tr>
<tr><td>Structure</td><td>Organisation</td></tr>
<tr><td>Phase I</td><td colspan="2"> 
</td></tr>
<tr><td colspan="3">Invalid and lack of chaining between the structural and organisation element</td></tr>
<tr><td colspan="3">Description of inaccurate attribute link
…This is a secondary structure because it is coiled into different shapes. This is tertiary because it is 3D…</td></tr>
<tr><td colspan="3">Description for invalid chaining between structural and organisation elements

Hair keratin and growth hormones are secondary structures (component) because they are coiled into different shapes (attribute). Haemoglobin, enzymes and antibodies are tertiary protein (component) because they have a 3D shape (attribute). Antibodies and haemoglobin can be quarternary as they are made up of more than 2 polypeptides.</td></tr>
<tr><td colspan="3">Description for chaining across the phase (indicated as 1)

A nucleus has a nuclear membrane (component). The membrane is made up of a phospholipids bilayer (attribute). So, the organic component is lipids (component). Mitochondrion also has a membrane (attribute) so the organic compounds that are involved are lipids (component). A vacuole stores water (functional) Chloroplast is made up of starch (component) because it carries out photosynthesis (process). The golgi apparatus and cell wall (L6 left blank).</td></tr>
<tr><td colspan="3">Description for chaining across the phase (indicated as 2)

An enzyme is a protein (attribute). Ribosomes synthesise enzymes. The enzyme is then sent to RER and RER transports protein to the golgi apparatus. The golgi apparatus modifies, packages and transport enzymes out of the cells.</td></tr>
</table>

C-Component F-Functional A-Attribute P-Process IA- Inaccurate link
IV-Invalid chaining
Indicated as 1 – Chaining to phase I and II
Indicated as 2 – Chaining to phase I

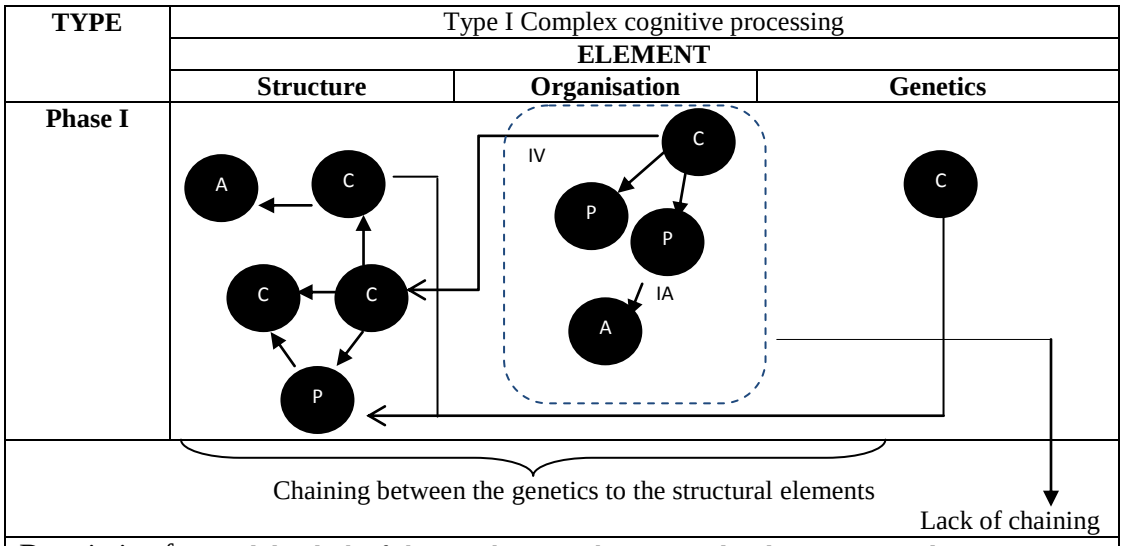
Figure 6.25. L6 Type I complex cognitive processing in phase III

It is clearly shown in Figure 6.25 that only a few links were identified. In addition, the attribute links in the structural element were inaccurate. This was probably due to the inaccurate attribute link of the secondary and tertiary level of protein in the structural element and different types of protein in the organisation element were invalidly chained. Based on L6's mechanistic reasoning, the protein structure for enzymes, antibodies and growth hormones were mismatched with the diagram given in the task. For example, L6 was unable to differentiate between tertiary and quaternary as he explained that both antibodies and haemoglobin can be quaternary or tertiary.

Nonetheless, L6 showed he was making effort in generating chaining by making sense of what he had learnt such as the chaining of the chemical composition of different organelles as well as the enzyme synthesis process in a cell which is shown in Figure 6.25. However, the chaining was invalid. Moreover, there was a lack of chaining across the phases as the attribute link for the golgi apparatus and cell wall was not identified.

Hence in phase III, L6 for most of the time managed to generate accurate links. The chaining between the elements attempted by L6, was invalid. Therefore in phase III it can be said that L6 was at Type I complex cognitive processing.

Similar to phase II, although L6 demonstrated a few network configurations in phase IV, the chaining was either an invalid one or there was a lack of chaining between the elements which is shown in Figure 6.26.



Description for invalid or lack of chaining between the structural and organisation elements

Cancer is caused by the growing number of cells (process). Non-disjunction occurs because the spindle fibre is imbalanced (attribute) and no crossing over occurs (attribute).

Description for chaining between the genetics to the structural elements

The genetics of nerve cells and liver cells are different because the liver will produce liver cells through mitosis, muscle cells will produce lots of muscle cells through mitosis. So the genetics are different. Sperm and ovum undergo meiosis where crossing over occurs. So the genetics are also different.

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

Figure 6.26. L6 Type I complex cognitive processing in phase IV

In Figure 6.26, the links generated were largely accurate. Nonetheless, the chaining was invalid. For example, in the application of cell division (organisation element) such as the formation of cancerous cells and non-disjunction, L6 chained the spindle fibre to imbalance (attribute link) and crossing over did not occur (process link) which suggested that he was uncertain of the links that he should chain to for non-disjunction. This is because non-disjunction is neither caused by the crossing-over process nor an imbalance of spindle fibres in cell division. The chaining demonstrated by L6 in his reasoning appeared to be more of trial and error as he tried to chain to links that he knew without assessing the validity of the chaining.

As for the genetics element, L6 assumed that the genetics of different cells were different even after learning cell division. Although he managed to chain between the structural and the genetics elements, the reasoning disclosed the invalidity of the chaining to the process link (mitosis and meiosis) in the structural element as shown in the excerpt below.

R : Why are the genetics different for different types of cells?
L6 : Because they are somatic cells and undergo mitosis. Sperm and ovum undergo meiosis where crossing over occurs. So the genetics are also different.
R : Why will somatic cells that undergo mitosis have different genetics?
L6 : Because the liver will produce liver cells through mitosis, muscle cells will produce lots of muscle cells through mitosis. So the genetics will be different.

(Excerpt from classroom discussion)

Based on the above excerpt, L6's reasoning revealed that the mitosis process only occurs among the same types of cells. L6 did not achieve type I complex mechanistic reasoning mainly due to the invalid or lack of chaining constructed by him. Therefore in phases II, III and IV, it can be said that L6 was at Type I complex cognitive processing.

Discussion

Learning is an experience that changes us as people; learning is not merely accumulating facts and information but is also a way of shaping our beliefs, ideas, and lives (Boaler, 2009). In research carried out by Zohar and Dori (2003), students with high academic achievements generally gained higher thinking scores as compared to their peers with low academic achievement. However, their findings also showed that low achievers net gained score was higher than the high achievers in one of the tests. Similarly, Yu, She and Lee (2010) in their research revealed that low achievers score better in non- traditional

test forms. A study conducted by Jensen (2008) also indicated that low-ability students have significantly greater reasoning gains with proper instruction. Is it true that mechanistic reasoning, one of the higher order thinking skills, is impossible to be infused among low achieving students? The literature and findings of students' mechanistic reasoning in the first section of this present study showed that it is possible. The first section of the findings revealed high and low achieving students' mechanistic reasoning in each phase. High and low achieving students demonstrated simple and complex cognitive processing in different phases which suggested that high achieving students are not always capable of generating complex cognitive processing in their mechanistic reasoning all the time and vice versa. High and low achieving students overall progression for the four phases of the Theory of Cell will now be discussed in the following section.

Overall Progression of Mechanistic Reasoning From Phase I to Phase IV among High and Low Achievers

In the previous section, the researcher reported the types of cognitive processing that the high and low achieving students experienced based on the links, chaining and the configuration. In this section, the researcher will discuss about the overall progression of high and low achieving students' mechanistic reasoning from phase I to phase IV. Several graphic representations are utilised to show their progression such as Figures 6.27 and 6.28 in line graph format.

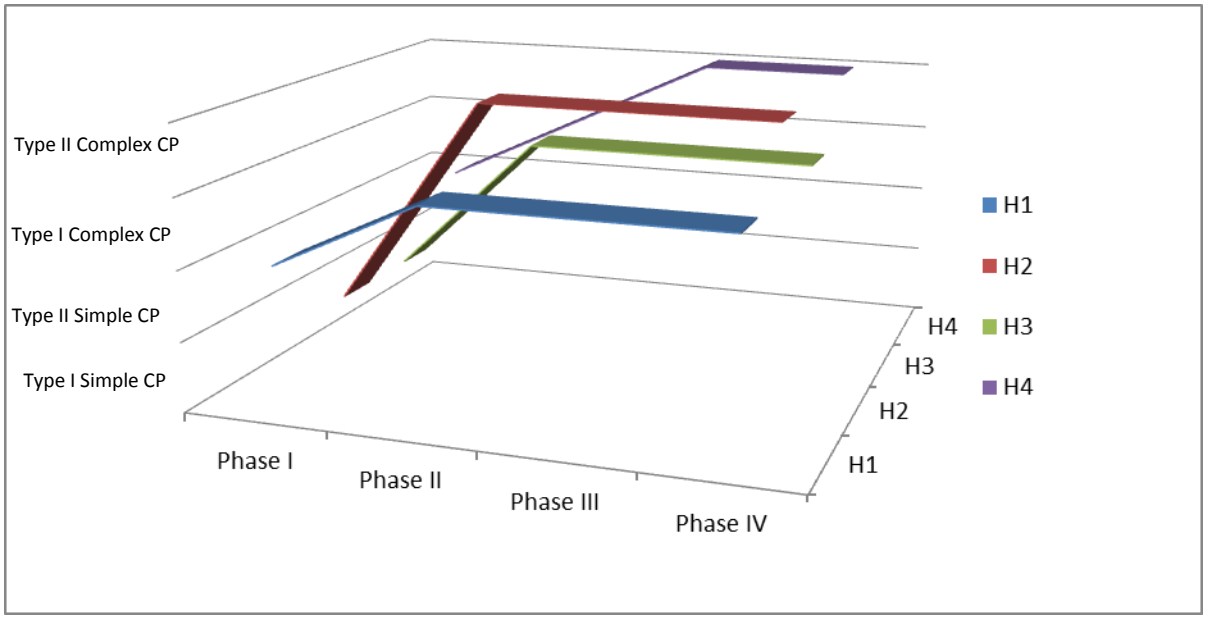
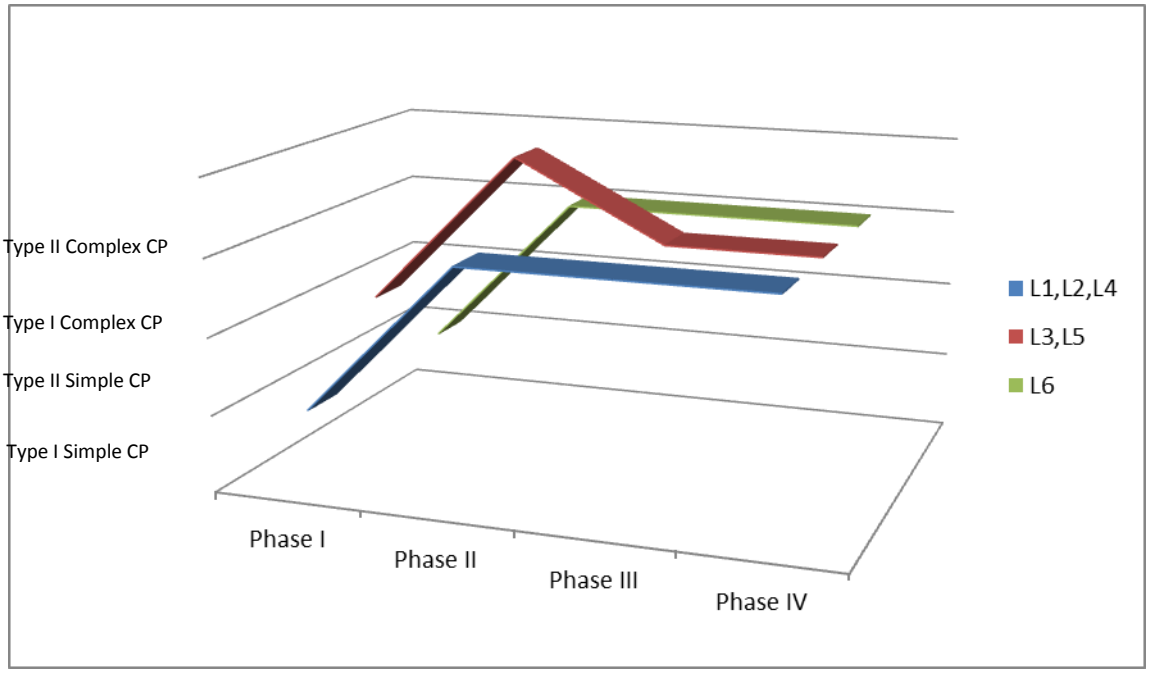


Figure 6.27. High achieving students' overall progression of mechanistic reasoning from phase I to phase IV



Figur 6.28. Low achieving students' overall progression of mechanistic reasoning from phase I to phase IV.

Based on the Figures 6.27 and 6.28, high and low achieving students do not show much difference in their progression. Both high and low achieving students either showed

steady progression whereby students were able to reach a certain level of mechanistic reasoning and maintain the reasoning at that particular level or display unstable progression in which the mechanistic reasoning is not maintained at a certain level. H1, H2, H3, H4, L1, L2, L4 and L6 showed steady progression in their cognitive processing while, L3 and L5 indicated unstable progression. Two high achieving students achieved and maintained Type II complex cognitive processing. However there were two low achieving students who achieved Type II complex cognitive processing but they failed to maintain this level of processing. The details of the progression among high and low achieving students will now be discussed.

Steady progression

As discussed above, the majority of the students showed a steady progression in their cognitive processing from phase I to phase IV, including H1, H2, H3, H4, L1, L2, L4 and L6. The box chart in Figure 6.29 clearly displays their progression.

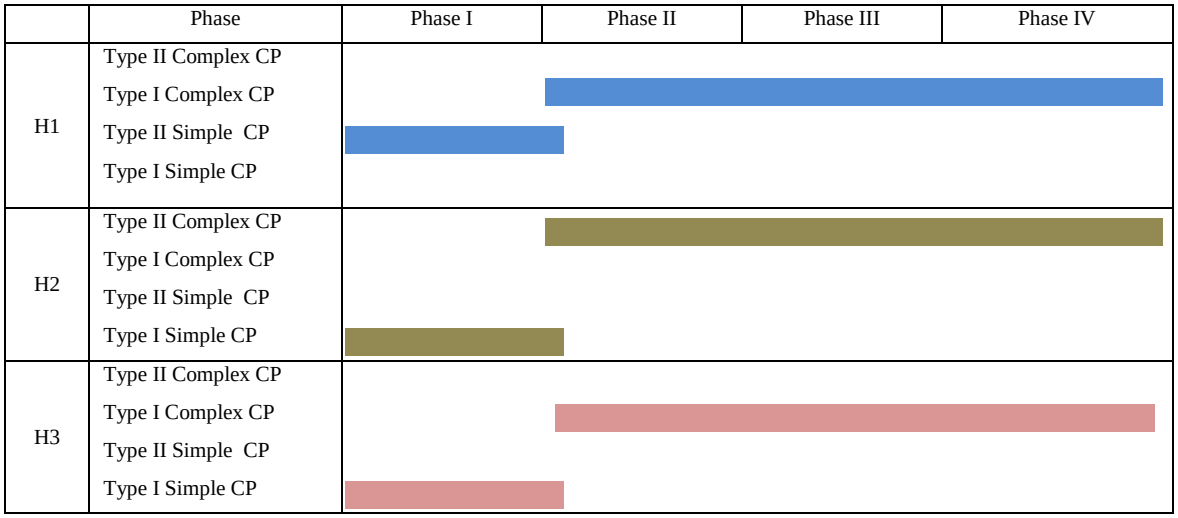


Figure 6.29. A box chart that represents students' steady progression from phase I to phase IV

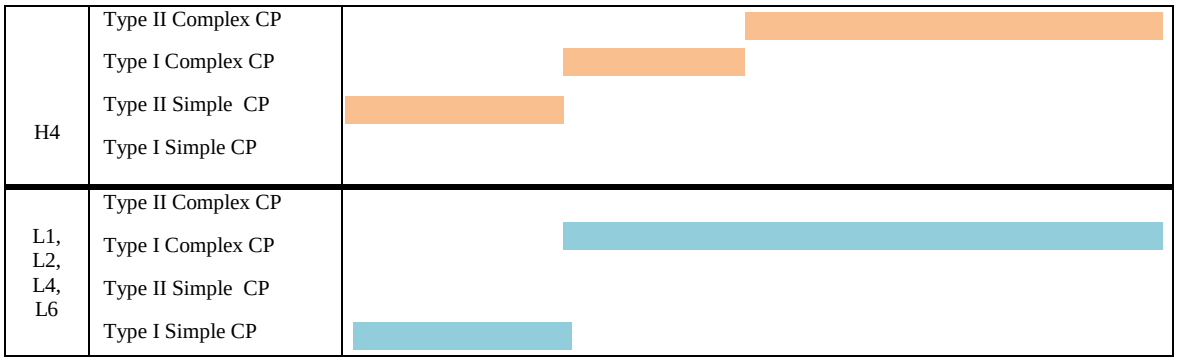


Figure 6.29. (Continued)

In phase I, both high and low achieving students began with a similar processing level which is either type I or type II simple cognitive processing. In phase II, the high and low achieving students had shifted to complex cognitive processing. Among these high and low achieving students, H3, L1, L2, L4 and L6 indicated a two steps progression in the cognitive processing. H3's mechanistic reasoning was categorised as Type I simple cognitive processing in phase I. As he proceeded to phase II, his mechanistic reasoning indicated a Type I complex cognitive processing. He was also able to maintain the Type I complex cognitive processing in phase III and phase IV. Similarly, L1, L2 and L4 also showed a 2 steps leap in their mechanistic reasoning which is from type I simple cognitive processing in phase I to type I complex cognitive processing in phase II and maintained at that level until phase IV.

H3 showed a huge leap which is a three steps leap in his mechanistic reasoning which is from type I simple cognitive processing in phase I to type II complex cognitive processing in phase II. He was also able to maintain at that level in phase III and phase IV.

H1 and H4 showed a one-step progression in their cognitive processing in phase II. Both the high achieving students started with Type II simple cognitive processing and progressed to Type I complex cognitive processing in phase II. However, H1 did not progress to type II cognitive processing in phase III and phase IV. Hence, his cognitive

processing was maintained at Type I complex cognitive processing. On the other hand, H4 advanced one more step to type II cognitive processing in phase III and maintained at this level in phase IV.

The details of the links and chaining as well as the types of configurations that could have contributed to the steady progression from phase I to phase IV is illustrated in Figure 6.30.

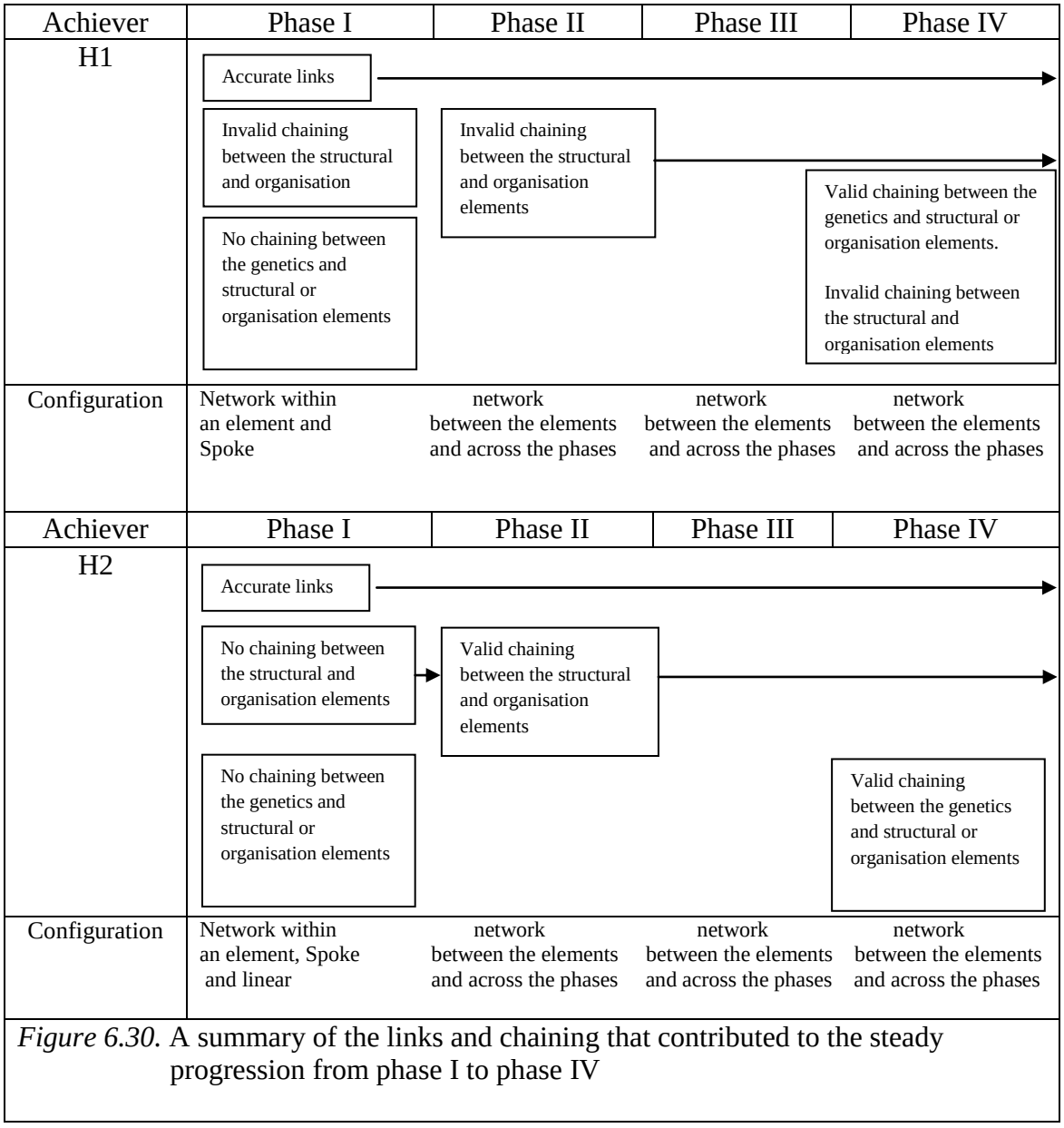
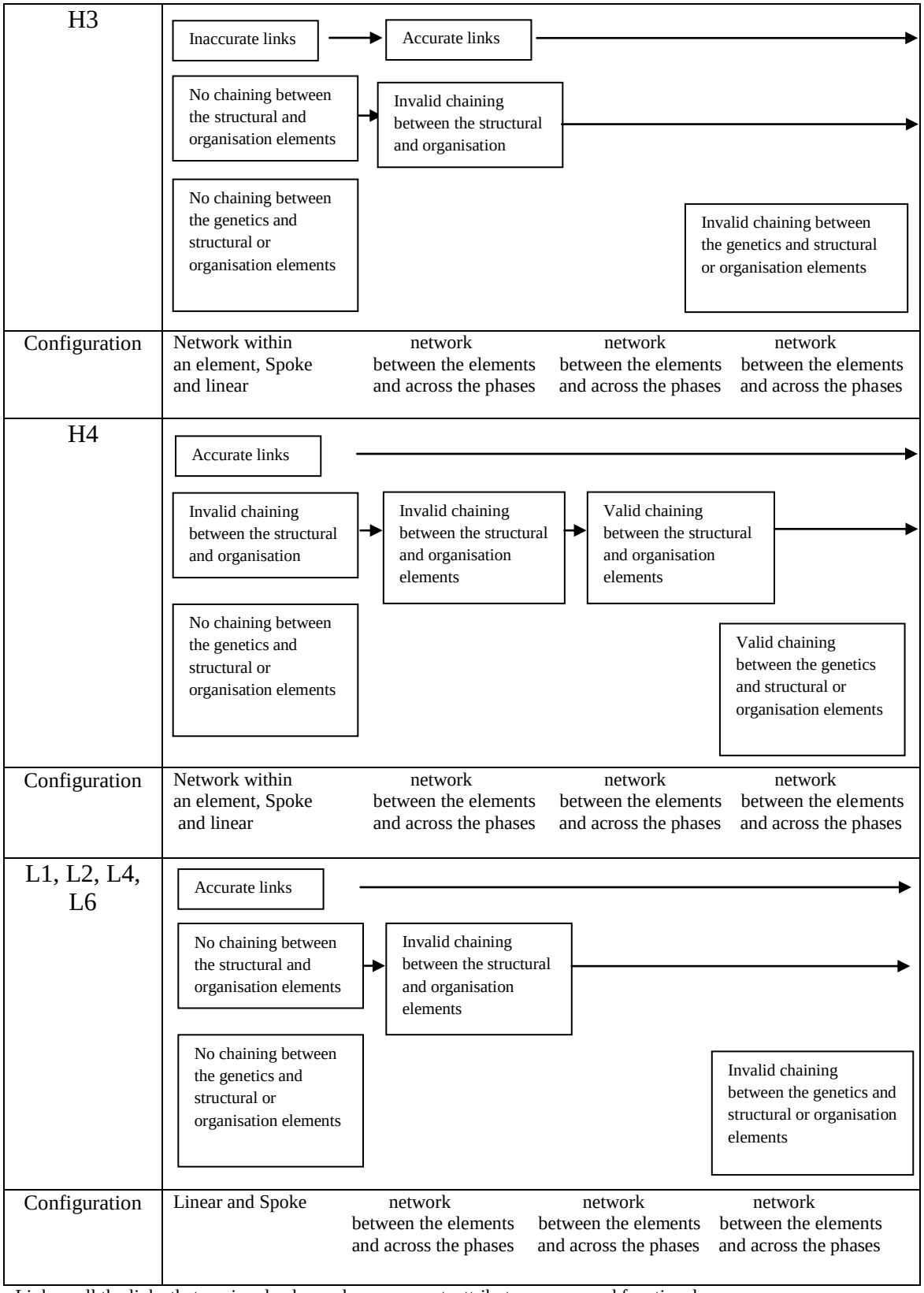


Figure 6.30. A summary of the links and chaining that contributed to the steady progression from phase I to phase IV



Links – all the links that are involved namely component, attribute, process and functional
→ maintain or same for the following phase

Figure 6.30. (Continued)

In phase I, the students generated spoke, linear and one or two network configurations within each element. This indicated students either performed invalid or no chaining between the structural and organisation elements. Furthermore, none of the students chained genetics to other elements. Consequently, their configurations had fewer network configurations but more spoke and linear configurations. Spoke and linear configurations are categorised as low hierarchy of configurations as they only showed single link (which is also discussed in chapter 5).

In the following phases such as phases II, III and IV, all of them demonstrated more network configurations between the elements and across the phases in all the phases which indicated that the chaining between the links and between the elements were constructed. Nevertheless, not all chaining were valid. For instance, although H1, H3, H4, L1, L2, L4 and L6 demonstrated network configurations in phase II which indicated chaining among the links between the elements; yet, the chaining was invalid (refer to Figure 6.30). Only H2 was able to demonstrate valid chaining in his network configuration in phase II.

H1, H3, L1, L2, L4 and L6's cognitive processing were maintained at the same level as type I complex cognitive processing for phases II, III and IV. Although they were still able to demonstrate network configurations in phases II, III and IV, the chaining in the configurations are invalid especially between the structural and organisation elements. In contrast, H2 and H4 were able to generate valid chaining between the elements and across the phases in phase III and IV. Therefore, their cognitive processing was maintained at the highest level which was Type II complex mechanistic reasoning.

Unstable progression

L3 and L5 showed unstable progression whereby their cognitive processing was not static from phase I to phase IV. This is shown in the box chart below.

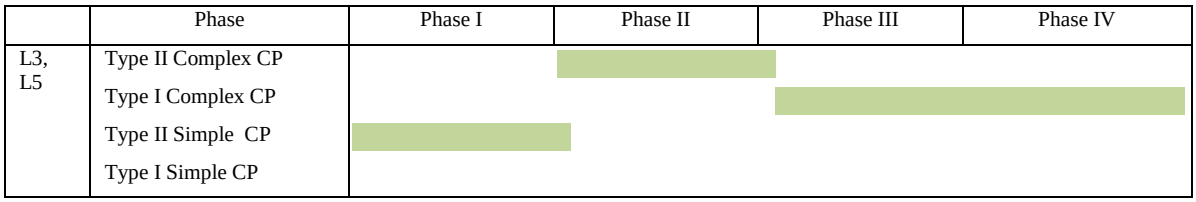
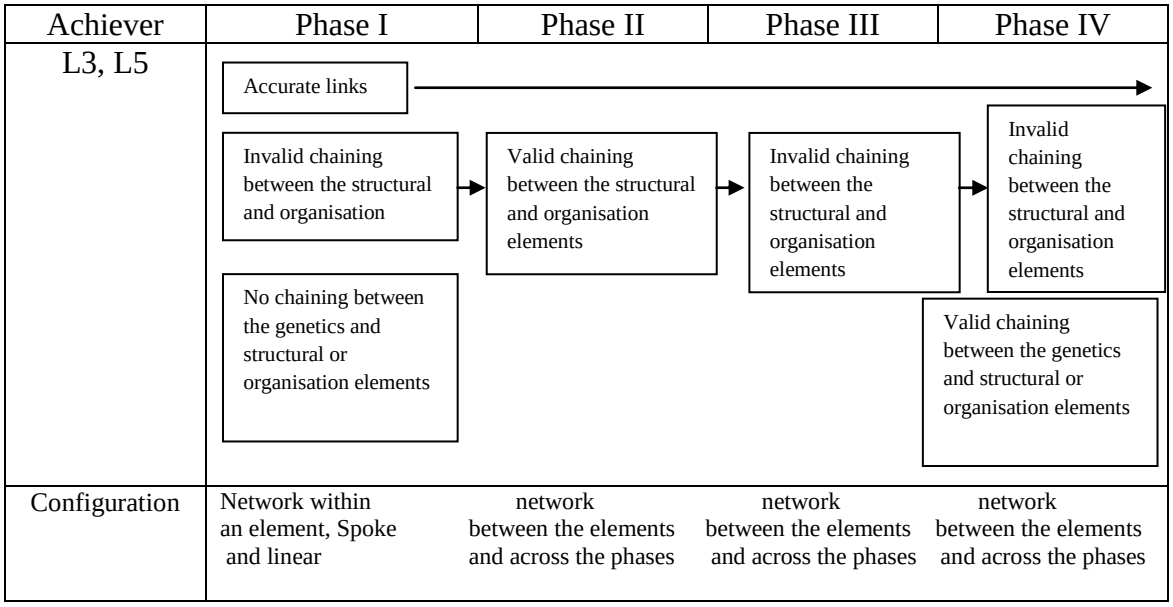


Figure 6.31. A box chart that represents students' unstable progression from phase I to phase IV

Similar to students who showed steady progression, students whose progression was unstable also demonstrated either Type I or Type II simple cognitive processing in phase I. Nonetheless, in phase II, all of them were able to leap two steps to form complex cognitive processing. L3 and L5, surprisingly, were able to leap from phase I type II simple cognitive processing to Type II complex cognitive processing in phase II.

However, L3 and L5's cognitive processing dropped two steps from type II complex cognitive processing to type I complex cognitive processing in phase III. In phase IV, L3 and L5's cognitive processing were maintained at type I complex cognitive processing. The instability in their cognitive processing also indicated the difficulty to predict their cognitive processing in the next level. The details of the links, chaining as well as the types of configurations that contributed to the unstable progression from phase I to phase IV are illustrated in Figure 6.32.



Links – all the links involved such as component, attribute, process and functional
→ maintain or same for the following phase

Figure 6.32. The details of the chaining, links as well as the types of configurations that contributed to the unstable progression from phase I to phase IV

In phase I, the students generated spoke, linear and network configurations within each element. This indicated students performed no chaining between the structural and organisation elements. Furthermore, L3 and L5 did not chain the genetics to other elements. Consequently, their configurations had fewer network configurations but more of spoke and linear.

As they proceeded to phase II, their configurations showed more than two network configurations which indicated chaining between the elements. Moreover, L3 and L5 were able to generate valid chaining in phase II.

In the discussion above, their processing declined in phase III. This might have been due to the chaining between the element and across the phases that formed the network configurations that were invalid. Hence, the students in unstable progression showed a fall in their processing in phase III.

In phase IV, although L3 and L5 were able to demonstrate valid chaining between the genetics and the structural element, the chaining between the structural and organisation elements were mostly inaccurate. Thus, their cognitive processing was maintained at type I complex cognitive processing.

Generally, two low achieving students who showed unstable progression failed to maintain type II complex cognitive processing as compared to two high achieving students who demonstrated type II complex cognitive processing in steady progression. Although a lot of the research has shown that high achievers might have better reasoning skills as they were able to select appropriate information (Cook et al., 2008; Countinho et al., 2005; Simons and Klein, 2007; Thomas and MacGregor, 2005), this present research has shown that, undoubtedly, high achieving students might perform better as there are two high achievers who were able to maintain at type II complex cognitive processing; however, low achieving students also demonstrated that they have 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. L3 and L5 also showed better chaining in their mechanistic reasoning in phase II as compared to other high achieving students.

Both high and low achieving students were categorised 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 require proper guidance even among the high achieving students. In the prolonged infusion, this might also assist the low achieving students to acquire the skills.

Apart from two high achieving students who showed advancement in their cognitive processing (achieved and maintained at type II complex cognitive processing), generally

high and low achieving students showed not much difference in their mechanistic reasoning. This suggested that low achieving students, despite constructing invalid chaining, are 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. Although prior knowledge is important for students to reason, low achieving students showed their efforts in making sense of their reasoning with the knowledge they had. This appeared to refute what most teachers believed that low achieving students were not suitable to be involved in higher order thinking skills in Abdullah Mohd Nor's (2009) and Zohar's research (2008). With prolonged engagement as well as suitable tasks given, this study showed that even low achieving students were able to reason mechanically although it might not be as excellent as the high achieving students. In addition, some low achieving students' mechanistic reasoning showed no difference as compared to some high achieving students. During the five months integration of mechanistic reasoning, students' cognition was highly challenge-based on the tasks given in the Living Cell Tool. The only difference between the high and low achieving students was that high achieving students showed steady progression while low achieving students encountered unstable progression in their reasoning.

Describing the progression of high and low achieving students across the four phases is not sufficient to describe the process that takes place in their cognition. Therefore, the students' cognitive structure will be discussed explicitly in the following unit.

High and Low Achieving Students' Representations for the Theory of Cell

In the previous section, the researcher revealed students' progression of mechanistic reasoning from phase I to phase IV. From students' progression of mechanistic reasoning,

this section will discuss about high and low achieving students' representations for the Theory of Cell. An organism's thoughts, experiences, and memories are said to be about objects and events in the world, and insofar as they are about them, they *represent* them (Sullivan, 2010). In this study, the representations can be taken as the outcomes that represent students' mechanistic reasoning. These representations appeared to be of increasing complexity. The representations identified are intuitive, assimilated, transformational and misinterpreted representations. These types of representations will now be discussed. Assimilated representations are further divided into simple assimilated representations and elaborated assimilated representations.

Intuitive representations

As mentioned earlier, some mechanistic reasoning demonstrated by high and low achieving students cannot be matched to any past scientific knowledge. The mechanistic reasoning was mainly based on their own assumption and less scientific-based. This is shown in Table 6.13.

Table 6.13

Example of Intuitive Representation Shown by H2 and L1

H2, Phase I, Genetics element	L1, Phase IV, Organisation element
Muscle cells and liver cells have different genetic information <u>because everything cannot be the same.</u>	Cancer is formed from malignant tumours when <u>something goes wrong.</u>

During phase I, when the genetics element is looked at, H2's mechanistic reasoning given- 'everything cannot be the same' – indicated no relevant scientific based reasoning.

Similarly in phase IV, when students were required to reason the formation of cancerous cells and the non-disjunction process in the organisation element, L1's mechanistic reasoning showed that he was unable to generate links and just stated that 'something goes wrong'. This indicated that students, at that particular phase, demonstrated type I processing (based on Craik and Lockhart, 1972) as they were unable to even match with their prior scientific knowledge.

Although not many examples of employing intuition in their reasoning occurred among high and low achieving students, the examples shown in Table 6.13 revealed that intuition in their reasoning have occurred whenever they encountered difficulties in reasoning mechanistically for certain tasks regardless of the phase. The examples also showed that intuition in mechanistic reasoning is not restricted to students of a certain level of achievement as both high and low achieving students demonstrated intuition as shown in Table 6.13.

Assimilated Representation

Assimilation is an important representation as it indicates students' capabilities in choosing and matching their past scientific knowledge in generating mechanistic reasoning; nonetheless, in several tasks they were only able to assimilate certain concept without any further elaboration. In this present study it is known as simple assimilated representations. This is shown in Table 6.14.

Table 6.14

Example of Simple Assimilated Representations Shown by H4 and L5

H4, Phase I, Organisation element	L5, Phase I, Organisation element
In metamorphosis of a tadpole, the tail will be replaced. Pancreatic cells produce enzymes. (functional).	Pancreatic cells have enzymes (functional).

In Table 6.14, H4 and L5 indicated that they were able to assimilate with their past knowledge which they had learnt during lower secondary science, for example pancreatic cells produce enzymes. Nonetheless, no elaboration was constructed even though enzymes are a type of protein. Without the elaboration, the students' mechanistic reasoning could not be sustained. Thus, they were unable to assimilate the organelles which could be found abundantly in pancreatic cells.

Another example indicating simple assimilated representations is when students were required to describe the cellular processes which take place in a cell such as in protein synthesis in phase I. This is shown is Table 6.15.

Table 6.15

Example of Simple Assimilated Representations as shown by L2 and L4

L2, Phase I, Structural element	L4, Phase I, Structural element
A Nucleus (component) controls the cellular activities (functional). Mitochondria generate energy for the cell (functional)… Ribosomes synthesis protein. Then, it is sent it to RER. (process).	A nucleus (component) controls the cellular activities (functional). Ribosomes synthesise protein …. Then, it is sent to RER. (process)

Based on Table 6.15, L2 and L4 were able to assimilate the function of each organelle. However, they were unable to relate the function in describing the protein

synthesis process (one of the cellular processes). Thus, as it can be seen in their written task above, there is no elaboration in describing the process. Students could only describe the protein synthesis process involving ribosomes and RER. The involvement of the golgi apparatus and mitochondria were absent in explaining the protein synthesis process.

Based on the examples in Table 6.14 and 6.15, simple assimilated representations mainly occurred in phase I. This is indicated in the beginning of the infusion of mechanistic reasoning. Some high and low achieving students were only able to assimilate with certain scientific knowledge in reasoning mechanically. Thus, they were unable to elaborate their mechanistic reasoning.

Elaborated assimilated representations within a phase

Some high and low achieving students' mechanistic reasoning indicated elaboration within a phase. They were not only able to assimilate with their previously learnt knowledge but also attempted to extend their mechanistic reasoning. Thus, their reasoning showed more than one network configuration. This is shown in Table 6.15.

Table 6.16

Example of Elaborated Assimilated Representations within a Phase as shown by H4 and L4

H4, Phase I, Structural element	L4, Phase I, Structural element
Ribosomes synthesise protein (functional). Then, it will be sent to RER. RER transports protein to the golgi apparatus in the form of **transport vesicles** (component). The golgi apparatus will modify, package and transport it out of the cell in **secretary vesicles** (component).Mitochondria generate energy	Ribosomes synthesis protein. Then, it will be sent it to RER. RER sends it to the golgi apparatus. The golgi apparatus processes, packages and transports the protein (process). ↓ Elaboration

Table 6.16 (Continued)

for the process because the process involves organelle (process). ↓ Elaboration

Based on Table 6.16, both H4 and L4 showed extension of their reasoning in describing the protein synthesis process. However, H4 demonstrated more elaboration in his mechanistic reasoning by compared to L4. H4 was able to elaborate his mechanistic reasoning such as identifying transport and secretary vesicles in explaining the protein synthesis process which was not seen among low achieving students. Furthermore, H4 was also able to assimilate the function of mitochondria in extending his explanation for the protein synthesis process which did not occur in L4.

Another example of elaborated assimilated representations within a phase was clearly revealed in phase II. This is shown in Table 6.17.

Table 6.17

Example of Elaborated Assimilated Representations within a Phase Shown by H2 and L3

H2, Phase II, Organisation element	L3, Phase II, Organisation element
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). ↓ Elaboration	The soil becomes dehydrated when more fertiliser is added (attribute).Water moves out from the plant by osmosis (process) because the plant has more water concentration (attribute). Finally, the plant wilts (process). ↓ Elaboration

Based on Table 6.17, H2 and L3 were able to match with the accurate concept which is osmosis in describing the wilting of plants. In addition, they were able to elaborate how the osmosis concept was related to the phenomena by identifying the concentration of water molecules in different regions.

According to the examples given, both high and low achieving students were able to extend their mechanistic reasoning. High achieving students might be able to have more elaboration as shown in the Tables above; yet, low achieving students also showed that they were able to elaborate their mechanistic reasoning. Furthermore, not all the high achieving students demonstrated more elaboration than the low achieving students as discussed above.

Elaborated assimilated representations across phases

Some mechanistic reasoning demonstrated by high and low achieving students' representations indicated elaboration from their mechanistic reasoning as they progress from phase I to phase IV. For example, in phase I, H4 was able to describe the properties for different organelles, for example mitochondria, as having a double membrane. As he progressed to phases II and III, he described further that the organic compounds that were made up of mitochondria were protein and lipids as the membrane was made up of phospholipids bilayer and transport protein. Table 6.18 indicated elaborated assimilated representations in H4's.

Table 6.18

Example of Elaborated Assimilated Representations across the Phases shown by H4 and L1

H4, Phase I, Structural element	L1, Phase I, Structural element
… Mitochondria have a double membrane…	A nucleus has a nuclear membrane. A cell wall is rigid. Vacuoles store water. Chloroplast carries out photosynthesis. The golgi apparatus transport protein, lipids and carbohydrates.
H4, Phase III, Organisation element	**L1, Phase III, Organisation element**
Mitochondria, has a membrane. The membrane is made up of phospholipids and transport protein. So, the organic compositions are lipids and protein. ↓ Elaboration	A nucleus has nuclear membrane and a DNA. Membrane is made up of phospholipids and transport protein. So, the organic components are lipids and protein. A cell wall is rigid as it is made up of carbohydrates, proteins and lipids. Chloroplast is made up of starch because it carries out photosynthesis. Elaboration ←

Similar to H4, L1 also showed elaboration from phase I to phase III. In phase I, L1 described the organelles, for example the cell wall, to its property (it is rigid). As he progressed to phase III, he described the organic compound which made up the cell wall as carbohydrates, proteins and lipids because it was rigid. Certain properties in describing the organelles also extended from phase I to phase III. For example, L1 described the nucleus as consisting the DNA which was not identified in phase I. This is shown in Table 6.18.

H3 showed elaboration in his reasoning in phases II and IV. For instance, in written task 1 in phase II, H3 reasoned that all substances moved across the plasma membrane by passive transport because the substances moved from a region of higher concentration to a region of lower concentration. Although in written task 6 he was able to state more

precisely the properties of the substances which were the substances that were large and polar that would be transported through the plasma membrane through facilitated diffusion, he still believed that all the substances should move from high to low. This is indicated in Table 6.19.

Table 6.19

Example of Elaborated Assimilated Representations across the Phases as shown by H3

H3, Phase II, Structural element	H3, Phase II, Organisation element
Ions, glucose and amino acids move across the plasma membrane by facilited diffusion because they move from a region of higher concentration to a region of lower concentration	Ions, glucose and amino acids in the small intestine move across the plasma membrane by facilitated diffusion. This is because they are large and polar molecules. In addition, they move from a region of higher concentration to a region of lower concentration

Elaboration

Similarly, in phase IV, H3 still thought that the genetics of different types of cell are different even though he had learnt the cell division process. This is also indicated in the Table 6.20.

Table 6.20

Example of Elaborated Assimilated Representations across the Phases as shown by H3

H3, Phase I, Genetics element	H3, Phase IV, Genetics element
Different cells have different genetics because they are different types of cells	Different cells have different genetics because the genetics in different types of cells are different. Only same types of cells will undergo mitosis

Extension

Low achieving students also demonstrated elaboration in their reasoning. For example, the synthesis of enzyme in L2 and L4's reasoning. They were only able to chain two organelles in the discussion of the protein synthesis process in phase I. However in describing the production of enzymes in phase III, they were able to elaborate enzymes with their organic compounds such as enzymes are protein (phase III), and then to organelles involved in protein synthesis such as the golgi apparatus, ribosomes and RER (phase I). This is shown in Table 6.21.

Table 6.21

Example of Elaborated Assimilated Representations across the Phases as shown by L2 and L4

L2 and L4, Phase I, Structural element	L2 and L4, Phase III, Organisation element
Ribosomes synthesise proteins. Then, they send it to RER. RER transports protein.	An enzyme is a type of protein. Ribosome synthesise proteins or enzymes. The enzymes are then sent to RER and RER transports protein to the golgi apparatus. The golgi apparatus processes and transports enzymes out of the cell. Mitochondria produce energy for the process to work. ↓ Elaboration

Transformational representations

Although in many occasions transformation and elaboration are inseparable, there was one example that indicated transformation in H4's mechanistic reasoning but with no elaboration. For example, in phase I, H4 assumed that bone can only be made up of bone cells. In phase III, his representations about cell organisation had transformed; however, he was only able to give an extra example of tissues during prompting which was shown in the Table 6.22.

Table 6.22

Example of Transformational Representations across the Phases as shown by H4

H4, Phase I, Organisation element
Bone is made up of bone tissues, and bone tissues come from bone cells.

H4, Phase II, Organisation element		
R	:	What types of tissues are small intestines made up of?
H4	:	Muscle tissues and... (silence)
R	:	Only muscle tissues?
H4	:	Em… I forgot the name of the other tissues. → Transformation

(H4, Excerpt from classroom discussion, Task 6, Phase II)

Based on Table 6.22, H4's mechanistic reasoning had transformed in phase II. However, he failed to elaborate his mechanistic reasoning by stating the types of tissues that made up the small intestines.

Both high and low achieving students demonstrated transformational representations across the phases from phase I to phase IV. For example, in phase I, H1 described that an organ was only made up of one type of tissue. This could be verified during an interview after having completing the task given to H1 in phase I as shown in Table 6.23.

Table 6.23

Example of Transformation Representations as shown by H1 and L4

H1, Phase I, Organisation element	L4, Phase I, Organisation element
R : Why you wrote the heart is made up of muscles tissues,? H1 : Because they need muscles to pump blood. R : Is the heart only made up of muscle tissues? H1 Yes. Muscle tissues are built from muscles cells. R : No other tissues?	A kidney is made up of kidney tissues. Kidney tissues are made up of kidney cells

Table 6.23 (Continued)

H1 : I don't think so. Pumping blood requires muscle tissues. (H1, Excerpt from interview, Task 3 Phase I)	
H1, Phase II, Organisation element	L4, Phase II, Organisation element
Small intestines are made up of muscle cells because of peristalsis. Then, they are also made up of blood cells because they consist of blood capillaries. Blood capillaries are also made up of epithelial cells. ↓ Transformation and elaboration (H1's written task 6, Phase II)	Small intestines are made up of epithelial and blood tissues because small intestines have red blood cells ↓ Transformation and elaboration

Probably due to the classroom discussion about the organisation of cells, H1's reasoning was transformed and elaborated in phase II. Thus, in phase II, he was able to state that multiple tissues made up one organ. Similarly, L4, in phase I, also assumed that an organ is made up of one type of tissue. However, in phase II, his reasoning transformed and extended by stating the different types of cells that made up the small intestines in the given task.

Another example of transformation representations was demonstrated by L1. In phase I, L1 generated a very simple property for the organelles, for example mitochondria is round in shape. As he progressed to phase III, he described the property of mitochondrion as consisting of a double membrane and not the appearance. As a result, he was able to further describe the organic compounds that made up mitochondria are proteins and lipids as the membrane is made up of a phospholipids bilayer and transport protein. This is shown in Table 6.24.

Table 6.24

Example of Transformation Representations Shown by L1

L1, Phase I, Structural element
Mitochondria is round in shape, the golgi apparatus has a curved shape and the cell wall is located outside the cell (weak attribute)
L1, Phase III, Organisation element
A nucleus (component) has a nuclear membrane and a DNA (component). A Membrane is made up of phospholipids and transport protein (attribute). So, the organic components are lipids and protein (component).Same as mitochondria, it has a membrane (attribute) and the organic compounds that are involved are lipids and protein (component). A cell wall is rigid (attribute) as it is made up of carbohydrates, proteins and lipids (component)… (L1's written task)
↓ Transformation and elaboration

The transformation showed by L1 enabled L1 to elaborate his mechanistic reasoning using knowledge learnt not only within a phase but also across the phases.

Another example of transformation representations is related to the genetics element. Table 6.25 shows an example of transformational representations by H2 and L6.

Table 6.25

An Example of Transformational Representations by H2 and L6.

H2, Phase I, Genetics element	L6, Phase I, Genetics element
The genetics for different types of cell are different because different cells have different genetics	The genetics for different types of cell are different because they are different types of cells.
H2, Phase IV, Genetics element	**L6, Phase IV, Genetics cells element**
The genetics for different types of cells are similar because mitosis produces genetically identical cells while the genetics of sperm and ovum are different because of crossing over	The genetics for different types of cells are different Liver will produce liver cells through mitosis, muscle cells will produce lots of muscle cells through mitosis
↓ Transformation and elaboration	↓ Transformation and elaboration

In phase I, H2 stated that the reason that causes the genetic differences in different types of cells was that the genetic composition was different. After learning mitosis and meiosis in phase IV, he reasoned that the genetics of different types of cells should be the same due to the mitosis process. However, some students also revealed misinterpretation in their transformation and elaboration for the genetics which will be discussed in the following section which is misinterpreted representations.

Misinterpreted Representations

Some students were able to assimilate with their past knowledge. Nonetheless, the matching of the information indicated misinterpretation of what they had learnt. Therefore the links generated are inaccurate. For example in phase II, L2 was able to state the consequence of excess fertilisers on a plant but he failed to reason mechanically. The consequence stated by L2 was also not related to any concepts learnt in phase II. This is shown in Table 6.26.

Table 6.26

Example of Misinterpreted Representations as shown by L6 and L2

L6, Phase IV, Organisation element	L2, Phase II, Organisation element
Non-disjunction occurs because the spindle fibre is imbalanced and there is no crossing over. (inaccurate process link) ↓ Misinterpret	If a farmer pours a lot of fertiliser on a plant, the plant will have hormone imbalance. ↓ Misinterpret

Another example was demonstrated by L6 in phase IV. Although L6 was able to generate related links by matching imbalance of spindle fibres and crossing-over to non-

disjunction which were learned in phase IV, the links generated by him indicated that he had misinterpreted the non-disjunction process as it was not caused by spindle fibre imbalance or no crossing over.

High achieving students also demonstrated misinterpreted representations specifically in phase I when they were required to reason why certain cells had certain organelles abundantly. Some high achieving students were able to generate links; yet, the links were inaccurate as they had misinterpreted the information. This is shown in Table 6.27.

Table 6.27

Example of Misinterpreted Representations as shown by H1 and H2

H1, Phase I, Organisation element	H2, Phase I, Organisation element
The metamorphosis of a tadpole needs ribosome (inaccurate component link.) because the tail is made up of protein (inaccurate attribute link) H1's written task → Misinterpret	**(The function of pancreatic cells and liver cells are unknown)** H2's written task
H1, Phase IV, Organisation element	**H2, Phase IV, Organisation element**
R :What makes you think that the tail is made up of protein? H1 :Hm… I think it is made up of protein. ↓ Misinterpret (H1, Excerpt from classroom discussion, Task 4 Phase I)	R :What about pancreatic cells and liver cells? H2 :Hm… I don't know. Pancreatic cells are for digestion (functional link)? ↓ Misinterpret (H2, Excerpt from classroom discussion, Task 4 Phase I)

Table 6.27 shows the reasoning given by the high achieving students. Although they were able to generate links; nevertheless, the reasoning indicated misinterpretation of their information. For example, H1 assumed that the tail of a tadpole is made up of protein which

is inaccurate. Similarly, H2 assumed that pancreatic cells are for digestion and not for producing enzymes.

Misinterpreted representations sometimes also occurred during transformation and elaboration. For example, in phase I, L6 elucidated that the genetic composition of the types of cells are different due to the different types of cells in phase I (Table 6.27). Although the mechanistic reasoning indicated transformation and elaboration by relating to mitosis and meiosis after learning the concept in phase IV, L6 still assumed that the genetics for different types of cells were different. His mechanistic reasoning revealed that he thought that only the same types of cells will undergo mitosis to form the same cells which indicated a misinterpretation of the mitosis process. This is because mitosis takes place after fusion of the sperm and ovum. Cells with similar genetics will undergo cell specialisation to form different types of cells.

The representations demonstrated by high and low achieving students revealed that their reasoning was not always accurate although they managed to assimilate, transform or elaborate within a phase or across the phases. This also revealed that the ability to transform and elaborate one's reasoning does not suggest that they will not misinterpret what they have learnt.

Discussion

The representations showed by students who represented the outcomes of the overall mechanistic reasoning, four representations emerged from their data. They are intuitive, assimilated, transformational and misinterpreted representations. These representations can occur in any phase of the infusion. For example, based on the students' mechanistic reasoning some misinterpreted representation occurred in phase IV. To date, there have been several studies on representations, but they mostly focused on knowledge

representations (Schnotz & Kürschner, 2008; Caravantes & Galán, 2011). Schnotz and Kürschner (2008) explained that there are two types of internal mental representations of what we have learnt which are depiction and perception-proximal representation. Depiction representation refers to text construction during the processing of information while perception-proximal representation refers to visual construction. Caravantes & Galán (2011) explained that knowledge representation uses conscious/explicit/symbolic elements that facilitate reasoning and unconscious/ implicit/sub-symbolic elements related to the processing of information. However, these representations do not explicitly describe the outcomes of mechanistic reasoning. Craver (2007) described representation in memory into four different levels, namely "the level of spatial memory," "the level of spatial map formation," "the cellular-electrophysiological level," and "the molecular level". Nonetheless, in the present study, the students' mechanistic reasoning representations do not reveal the hierarchical levels from phase to phase. Description from Sloman and Fernbach (2011), on the other hands, shared some similar views on representation for reasoning. He argued that people reason about a complex system in three ways: firstly, they are selective in searching information. Secondly, people will try to take more information into account which is a simple linear form. This is equated with the simple assimilated representation in this study. Finally, people will go beyond a simple linear form to build a mental model that reflects a causal structure which is elaborated assimilated representations in this current study. However, there are three types of representations which emerged from the data that have not been described in the literature. They are intuitive, transformational and misinterpreted representations.

Summary

Based on the above findings, it could probably be summarised that, each individual student from the high and low achieving groups were able to generate mechanistic reasoning. The majority of the students generated type I simple cognitive processing in the beginning of the infusion (Phase I). This indicated that there is no difference in their mechanistic reasoning for the different achievement groups in phase I. Although high achieving students might generate more links than the low achieving students, students from both achievement groups were unable to generate valid chaining between the elements in the beginning of the infusion. However, students began to perceive the chaining in phase II and the subsequent phases. As a result, their cognitive processing indicated either type I or type II complex cognitive processing. The first section of the findings revealed the details on how students generated the links, chaining and configuration.

When students' individual mechanistic reasoning was scrutinised further, their progression over time in both high and low achieving students in the present study showed that most of them are able to generate steady progression. Some high achieving students might indicate better mechanistic reasoning than the low achieving student as two high achieving students were able to reach Type II cognitive processing and maintain at that level; nonetheless, low achieving students also revealed that they were capable of learning the high order thinking skills with proper guidance and support in a prolonged period of time.

The representions of the students' mechanistic reasoning give an overview on the overall outcomes of their mechanistic reasoning. Four types of representations emerged from their data. They are intuitive, assimilated, transformational and misinterpreted representations. The findings of this study seemed to reveal that the representations occur

throughout the phases. In addition, students' mechanistic reasoning from both achievement groups showed the four types of representations. This indicated that there it is possible that high achieving students demontrasted intuitive representation.

The next Chapter 7 will discuss the conclusion, implications as well as what possible future studies can be conducted.