CHAPTER 3

CONCEPTUALISATION OF THE STUDY

Introduction

This chapter will mainly focus on how the current study is framed and will discuss the underlying theoretical framework underpinning this study. The study of the Theory of Cells is prominent in Biology as the cell is the basic unit of life. However, due to lack of mechanistic reasoning, most students may not understand the cause and effect relationship between the Theory of Cell and its biological processes. Research into explicating the relationship among processes of Biology continues to show that students have difficulties particularly when two or more concepts are engaged (Cohen & Yarden, 2009; Flores, 2003, Kiboss et al., 2004; Songer & Mintzes, 1994). Hovardas and Korfiatis (2006) and Verhoeff, Waarlo and Boersma (2008) showed that to acquire coherent conceptual understanding of cell biology, higher order thinking skills such as mechanistic reasoning is necessary. However, Warburton and Torff (2005) and Torff (2006) pointed out that teachers favour low order thinking skills activities over high order thinking skills (HOTS) for low achieving students in their studies. The results also suggested that low achieving students may be exposed to fewer high order thinking skills (HOTS) activities in schools. The results were consistent with the research conducted by Zohar (2008). Thus, this present study investigated high and low achieving students' mechanistic reasoning. The framing of the conceptual framework will be further discussed in the following section.

Conceptual Framework of Study

There are altogether three parts to this research namely (i) exploring and describing high and low achieving Form Four students' mechanistic reasoning related to biological processes using the Living Cell Tool, (ii) describing the progression of mechanistic reasoning over time among high and low achieving Form Four science students and (iii) describing the emergent representations of mechanistic reasoning among high and low achieving Form Four science students. The researcher will discuss in this section how these parts of the study have been conceptualised.

There are numerous studies on students' difficulties in biology in the past two decades which are related to the Theory of Cell (Barman & Stain, 2008; Lazarowitz & Lieb, 2005; Lazarowitz & Penso, 1992; Marbach-Ad & Stavy; 2000; Odom & Barrow, 1995; Wang, 2005; Westbrook & Marek, 1991) and is shown in Table 3.1. The cell as a fundamental topic in biology is characterised as difficult to be understood by students. However, most of the biological processes occur at the cellular level. Therefore, if students do not understand cell processes, most of them would have difficulties in comprehending other biological concepts and might build up alternative frameworks as they progress.

Table 3.1

Students' Learning Difficulties in Biological Processes which is related to the Theory of Cell

Year	**Author**	**Contents**
1999	Barak et al.	Students' understanding of biological processes
2000	Lewis et al.	Cell and genetic
2000	Lewis et al.	Cell and cell division
2000	Marbach-Ad and Stavy	Cell and genetic
2001	Wynne, Steward and Passmore	Meiosis in solving genetics problems
2003	Panizzon	Cell and diffusion

Table 3.1 (continued)

Year	Author	Contents
2003	Flores	Cell and its processes
2006	Lazarowitz and Lieb	Cell and biological processes
2007	Saka et al.	Cell and gene
2007	Wang	Cell and transport system in plant
2008	Barman and Stein	Cell and interrelationships among organisms
2008	Riemier and Gropengieβer	Cell and cell division
2009	Taylor and Jones	Cell and surface area to volume ratio
2009	Cohen and Yarden	Cell is to be studied longitudinally
2012	Williams, DeBarger, Angela, Montgomery, Zhou and Tate	Genetic inheritance and cell division
2012	Oczan, Yildrim and Ozgur	Cell and cell division

Why do we learn about the cell as a leading topic in general science and biology? This is because the knowledge of biological processes can only be accurately achieved if students comprehend the Theory of Cell. This comprises the cellular component, the functions of the component and the connection between these components that explain the processes. The cellular components, functions and processes often remain fragmentary because they are mainly drawn from the subcellular level and not adequately integrated with concepts at the cellular and organism level (Verhoeff, 2008). This explains why students often fail to establish a connection between the Theory of Cell and cell processes.

Why do students fail to assimilate the Theory of Cell to cell processes? Taylor and Jones (2009) explained that this is due to a lack of higher order thinking skills such as mechanistic reasoning. Engeström (1994) stated that facts and classification alone are insufficient when procedures also and processes must be described as biology is all about processes. A network indicating the functional connections and interaction is required to tie it together. An unconnected set of facts will be soon forgotten. Mechanistic reasoning is one of the most fundamental cognitive processes that underpin all higher-order activity (Jonassen & Ionas, 2008). Without conceptually explaining the underlying mechanisms, learners will not able to build a coherent conceptual model of domain content (Jonassen &

Ionas, 2008). In learning cell biology, students most of the time focus on structures rather than processes, although an understanding of biological processes in cells has been recognised as being essential for a comprehensive understanding of biology (Verhoeff, et al., 2008). Hence, when dealing with the 'why' questions (process questions), students tend to answer them with teleological reasoning due to a lack of mechanistic reasoning (Abrams et al., 2001). Much research has highlighted the importance or the strategies of mechanistic reasoning which is shown in Table 3.2 (Abrams et al., 2001; Darden, 2002; Darden & Craver, 2002; Glennan, 2002; Craver, 2001; Jonassen & Ionas, 2008; Janssen & de Hullu, 2008; Machamer et al., 2000; Russ, 2008; Thargard, 1998). The present study also explores students' mechanistic reasoning in constructing coherent biological processes with the Theory of Cell, but with an emphasis on high and low achieving students.

Table 3.2

Previous Research in Mechanistic Reasoning

Year	**Author**	**Contents**
1991	Ploger	Study on reasoning and gain coherent understanding of biological mechanisms
1997	Douvdevany et al.	Develop diagnostic instrument to determine junior high-school science teachers' understanding of functional relationships within the "living cell"
1998	Thagard	Explaining diseases: correlations, causes, and mechanisms
2000	Machamer et al.	Thinking about mechanisms
2001	Abrams et al.	The how's and why's of biological change: learners neglect physical mechanisms in their search in meaning
2001	Southerland et al.	Understanding students explanation of biology phenomena (types of reasoning utilised)
2001	Craver	Role functions, mechanisms and hierarchy in giving reason
2002	Glennan	Rethinking mechanistic explanation
2002	Darden	Strategies discovery mechanisms
2002	Darden and Craver	Strategies in discovery mechanism of protein synthesis

Table 3.2 (Continued)

Year	Author	Contents
2008	Jonassen and Ionas	Designing effective support for causal reasoning
2008	Janssen and de Hullu	A toolkit for stimulating productive thinking
2008	Russ et al.	Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse
2010	Howick, Glasziou, Aronson	Mechanistic reasoning in evidence-based medicine
2012	Bolger, Kobiela, Weinberg and Richard	Children's mechanistic reasoning

There is literature which states that high performing students have a higher ability of reasoning. For example, Simons and Klein (2007) indicated that higher-achieving students scored better in solving problems than lower-achieving students. Thomas and MacGregor (2005) mentioned that high achievers tend to be effective in organising and coordinating their information. They will be able to engage themselves in deep, rich thought. On the contrary, low achievers are slow and engage in shallow ideas with little questioning and exchange of ideas. Cook et al. (2008) stated that the knowledge that novice learners have is not heavily interrelated and not hierarchically organised into a framework to make sense of new information. Therefore, they find it hard to connect the knowledge they have learnt. On the other hand, experts construct cognitive schemes that are easily retrieved. They are better in linking their knowledge which is related to current content as they are able to choose appropriate schema to help understand new information. Similarly, Stamovlasis and Tsaparlis (2005) claimed that high achievers have higher information processing ability to help them to familiarise with the science materials they have perceived compared to low achievers. Is performance in Science achievement consistent with performance in reasoning skills? While, there is literature which shows that some teachers believe that reasoning can only be taught among high achieving students (Zohar et al., 2001; Zohar & Peled, 2007), research has also indicated that enhanced reasoning in low-achieving students could help them to develop higher order thinking (Zohar & Peled, 2007; Simon & Klein, 2007). Therefore, more explicit information needs to be explored among high and low achieving students' mechanistic reasoning in learning biological processes which are related to science.

Varying classroom activities can enhance mechanistic reasoning. For example, external representations (for example, mind maps and models) are the basis of strategic scientific thinking and requires diverse mental thought such as planning, analysing data, collecting data, collaborating, visualizing and modelling (Jonassen, 2003). Verhoeff et al. (2008) stated that the use of models is essential because, in biology, structures and processes at different levels of biological organization are often abstracted into models. With the help of models, students can perceive and visualize the relationship among the biological processes at a cellular level which is sophisticated to the students. However, Sins et al. (2009) claimed that students should be allowed to construct their external representations by themselves, as they can reflect not only upon the science content they are supposed to learn but also upon the nature of their own knowledge. Jonassen (2003) contended that from any form of cognitive task analysis is necessary to engage students' reasoning about the biological concept.

Investigating students' mechanistic reasoning in developing a coherent understanding of the Theory of Cell and biological processes, could contribute valuable information on how students link biological processes with the Theory of Cell. This could also fill in the gap where research associated with mechanistic reasoning is inadequate. Whilst teachers and researchers could benefit from this study, this study could also inform students as how they could learn biology as whole. In addition, students could be likely to realise the importance of the cell and the biological processes that take place in the cells through the Living Cell Tool used in the study. The overall conceptual framework is as illustrated in Figure 3.1.

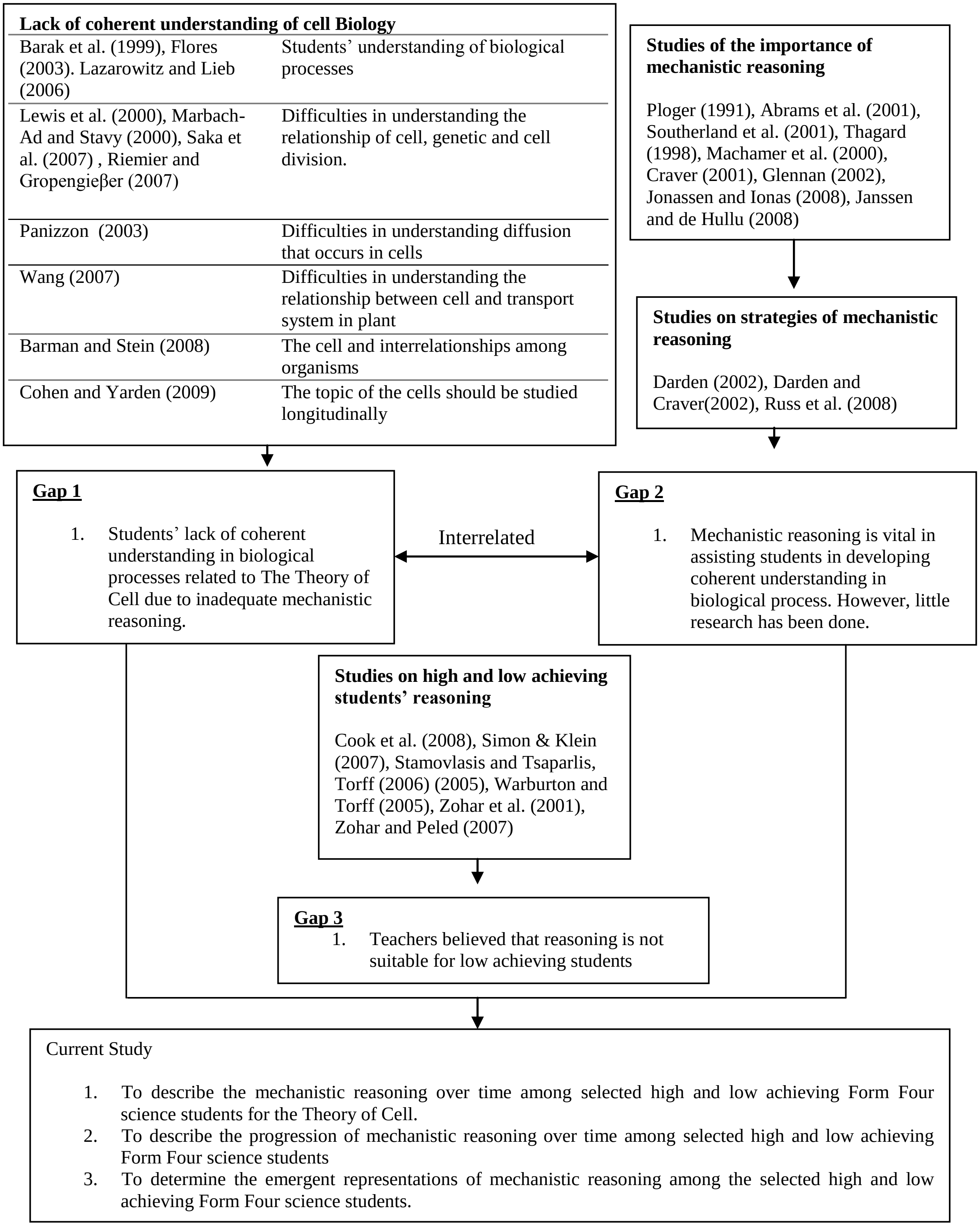

Figure 3.1. Conceptual framework for the study

Figure 3.1 shows that students' lack of understanding of cell biology is usually related to a lack of higher order thinking skills (HOTS) such as mechanistic reasoning which is the first gap in the present study. While mechanistic reasoning has been recognized as an important higher order thinking skill which could help students to develop coherent understanding, much research has been focused on the strategies. This led to the second gap where mechanistic reasoning was rarely exposed to students. Further reading showed that higher order thinking skills such as mechanistic reasoning is seldom implemented in schools because research suggests that teachers believe that higher order thinking skills are not suitable for low achieving students. Hence, the third gap that emerged was how true is this statement? Is it true that all low achieving students are unable to have mechanistic reasoning even with prolonged infusion? To investigate these gaps, the researcher has put forward several objectives for this present study in Chapter 1.

Proposed Theoretical Framework for Mechanistic Reasoning in the Context of Activity Theory for Biological Processes which are related to The Theory of Cell

Osborne (1996) said that epistemology does matter in science education because the answer to the question "how do we know" is an important aspect of the account of science. The theoretical framework underpinning this study encompasses the Theory of Investigative learning (Engeström,1994) supported by Vygotsky's (1984) Zone of Proximal Development (ZPD) and Craik and Lockhart's (1972) Levels of Processing. All theories utilised play an important role in explaining how reasoning is generated.

Theory of Investigative Learning

Based on Engeström's theory (1994), learning which is a mental and practical activity of the student is more complicated than mere "reception" and "storing". Students always end up correlating and merging newly acquired material into their ongoing activities and earlier construction. Through this kind of interpretation and construction, meaningful learning occurs. The knowledge acquired is meaningful to students if new knowledge and new tasks run into and merge with the learner's activity and former knowledge. The weaker this connection, the less meaningful the matter is to students and the easier it is forgotten. In learning biology, likewise, if students tend to "store" all the facts in biology without making connections among the topics they have learnt, they will encounter difficulties when facing questions involved with several biological concepts.

The Investigative Learning Theory emphasises both the historical development of ideas as well as the active and constructive role of individuals. Its founder was Engeström with its roots in the Soviet psychologist Vygotsky's socio-constructivist theory. Engeström expanded the basic Vygotskian triangle which aimed to highlight the importance of interaction between the learner, object and instruments. Figure 3.2 shows the basic structure of the Investigative Learning Theory.

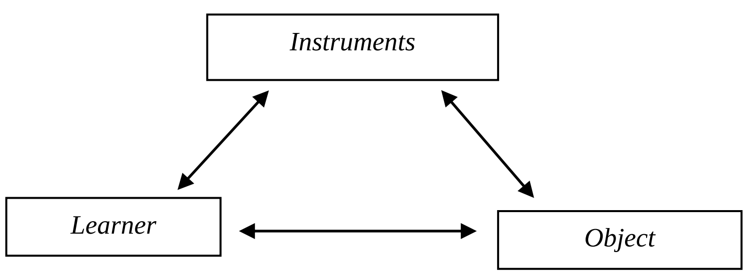

Figure 3.2. The basic structure of the Investigative Learning Theory (Engeström, 1994)

The learner of the activity is the individual or group of actors engaged in the activity whereas the object will be a problem or phenomenon needing explanation. In this study, the learner refers to the high and low achieving students. The object refers to a task that needs to be mastered by the learner and also to the mechanistic reasoning in developing a coherent understanding of the Theory of Cell in this study. With regards to the present study within the Theory of Cell, several topics were investigated. They are cell components, substances across the plasma membrane, chemical composition of the cell and cell division respectively. The investigation of the mechanistic reasoning of these topics required an instrument to assist students' learning. In this study, the infusion of mechanistic reasoning was aided by an instrument which is known as the Living Cell Tool (which will be explained in Chapter 4). Daniels (2001) explained that an instrument is created by the adult (in the present study, adults refer to teachers) by which the children (the students) can participate in the activity before they actually do it alone.

A learning process, through which the learner receives and masters the object, is a mental and practical activity which is more complicated than mere "reception and "storing" (Engeström, 1994, pg. 12). Engeström utilised constructivism in explaining students' learning wherein students literally construct their own explanation of different phenomenon. Students will always actively select and interpret information to merge into his or her ongoing activity and earlier construction so that the learning makes sense to them. In this present study, the learner comprises high and low achieving students. Hence, how high and low achieving students construct their own explanations will be explained by Vygotsky's Zone of Proximal Development. Both high and low achieving students begin with their own existing prior knowledge in their own zone of proximal development (ZPD) which is shown in Figure 3.3.

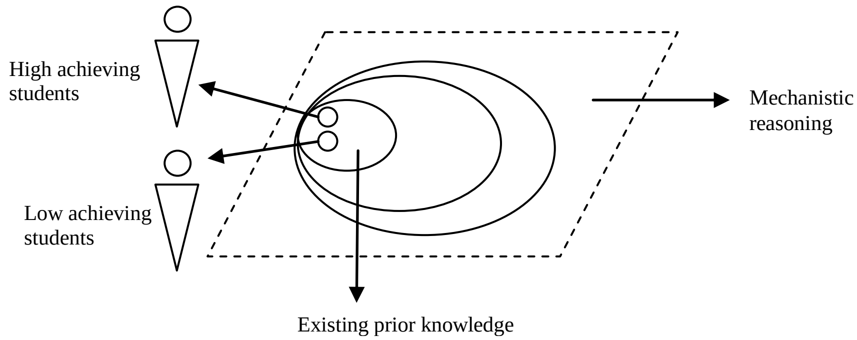

Figure 3.3. Zone of proximal development of high and low achieving students (learners)

In order to let high and low achieving students actively participate in the activity, an instrument is needed to initiate the learning process. Since students are not familiar with mechanistic reasoning, an instrument is required to facilitate the infusion. The instrument in the context of the present study is known as the Living Cell Tool. The basic structure of the Investigative Learning Theory adapted in the present study is shown in Figure 3.4.

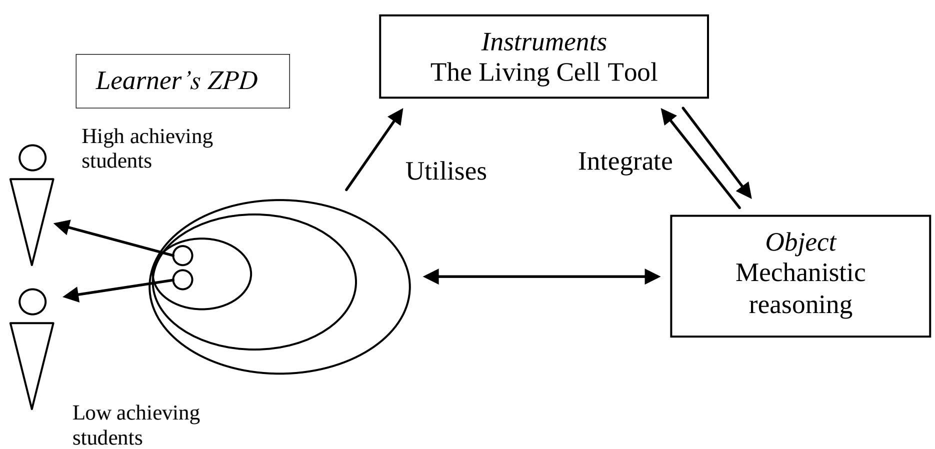

Figure 3.4. The basic structure of the Investigative Learning Theory and Vygotsky's zone of proximal development in infusing mechanistic reasoning

When learning of the Theory of Cell (for example cell structures and components) begins, high and low achieving students will analyse the phenomena and search for internal relationships to explain the structure of the knowledge necessary for them to link their existing knowledge together. They might relate their science knowledge acquired during lower secondary to the new information being taught in Form 4. During this stage, the teacher uses the tasks related to mechanistic reasoning in the instrument to assist students' mental activities so that they will actively reason mechanistically to relate their prior knowledge to the newly acquired information about the cell. This is known as orientation (Figure 3.5).

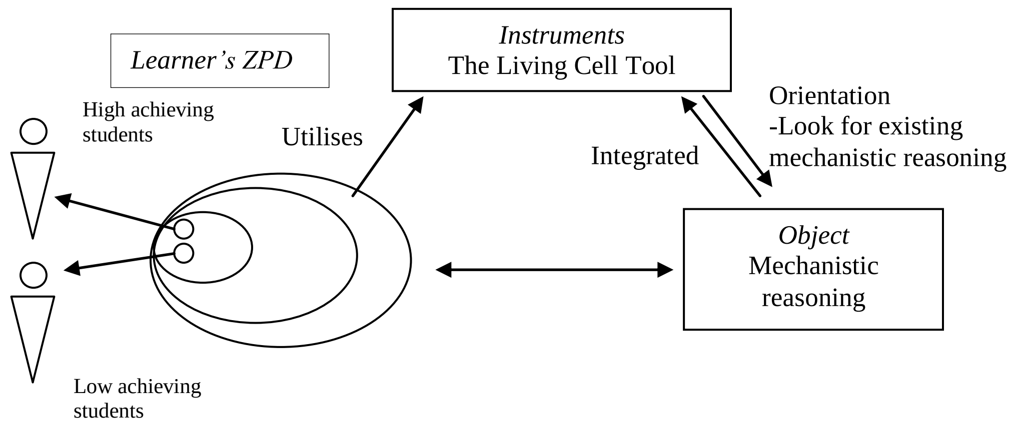

Figure 3.5. Preliminary stages of the Investigative Learning Theory

This is followed by internalisation when students organise and explain the parts and details of a system, which ultimately, is integrated into the learner's mind. As in the present study, students' prior knowledge of the cell structure will be triggered during the answering of questions in the Living Cell Tool's tasks (orientation) and subsequently will help them make connections between their prior knowledge and new pieces of information. Lastly, new mechanistic reasoning about cell structures will be internalised in their mind. During this process, without realising it, students are actually infusing mechanistic reasoning. Through this process, high and low achieving students' ZPD might shift. Figure 3.6 shows the internalisation stage in the Investigative Learning Theory.

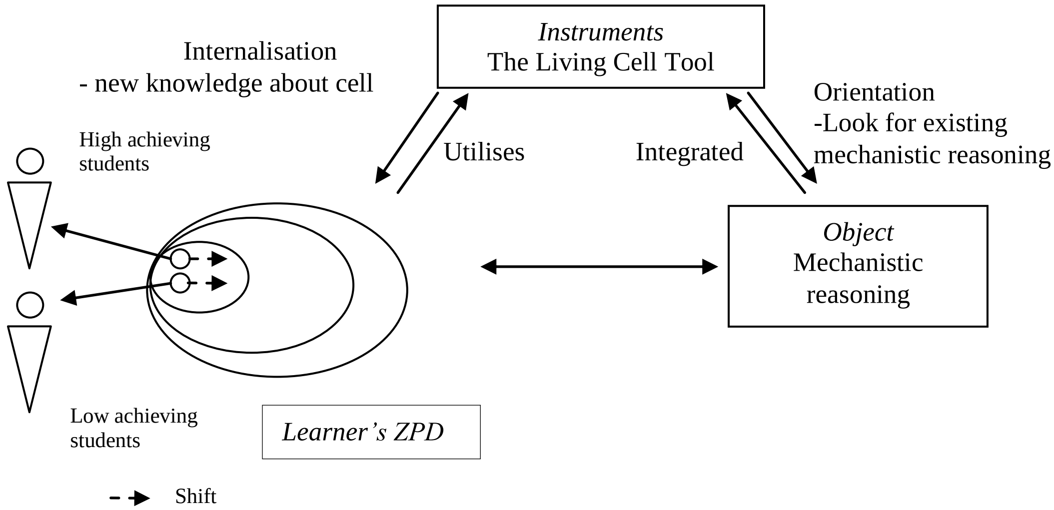

Figure 3.6. Internalisation stage in the Investigative Learning Theory

Inevitably, internalisation and externalisation is inseparable in the learning process. Externalisation is the application of reasoning in solving a problem, influencing the change in the surrounding reality and producing innovations. Externalisation is an essential condition for testing and evaluating of the new knowledge that students have engaged in. For instance, after the integration of mechanistic reasoning in learning the function of the cellular components, students will be asked to complete another task in the Living Cell Tool. This is about the inter-relating of the organelles in a cell. Learners will have to utilise what they have learnt in the previous lessons to externalise the new problem. When externalisation occurs, the learner will ponder upon a solution for the problem and reconstruct his/her explanations. It can be said that students' mechanistic reasoning is being evaluated and enhanced in a novel situation. During externalisation, high and low achieving students' reasoning will be evaluated. If students are not able to interact meaningfully with the Living Cell Tool, their ZPD will only be maintained at the same level. In contrast, if high and low achieving students were able to successfully integrate mechanistic reasoning, their ZPD is expected to shift and they will be able to externalise regardless of accurate or inaccurate mechanistic reasoning. Figure 3.7 shows the externalisation stage in the Investigative Learning Theory.

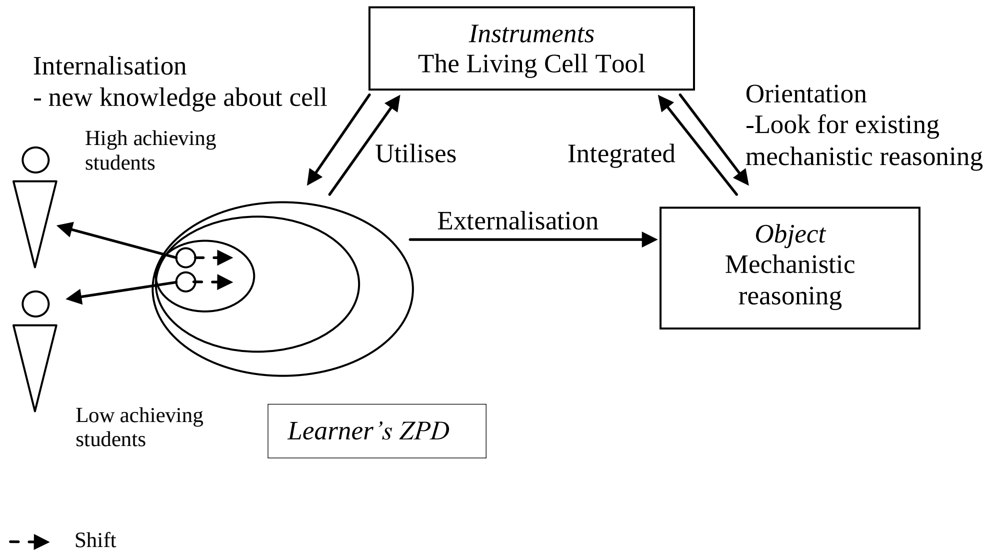

Figure 3.7. Externalisation stage in the Investigative Learning Theory

Meanwhile, students will evaluate critically the validity and usefulness of the explanatory activities during or after externalisation takes place. This is known as critique and control. Students will examine their own learning by organizing and interpreting the information on the basis of the newly acquired knowledge. The distinctive characteristic in this stage is that students are able to analyse the outcomes, identify the mistakes and strong points. For example, after completing the tasks for connecting the functions of cellular components, activities such as discussions and presentations will be carried out in order to let students consciously check their own mechanistic reasoning for that topic. New questions might be raised by the students during discussions for further investigation. During the critique and control process, when students constantly evaluate their learning through classroom discussions, this collaboration will indirectly influence the high and low achieving students' ZPD. Their ZPD might shift probably due to learning from the more knowledgeable one. For example, the low achieving student might benefit from the high achieving students while the high achieving students might benefit from their peers or promptings from the teacher through classroom discussions.

While students revise their mechanistic reasoning used in a new situation, they are actually reconstructing their knowledge. This newly acquired information from analysing his/her own learning will replace the former knowledge that he further re-internalized. Figure 3.8 shows the complete steps in the Investigative Learning Theory in infusing mechanistic reasoning.

The steps in the Investigative Learning Theory will be repeated for all the following learning topics which are from the movement of substances across the plasma membrane, to chemical composition of cells and cell division.

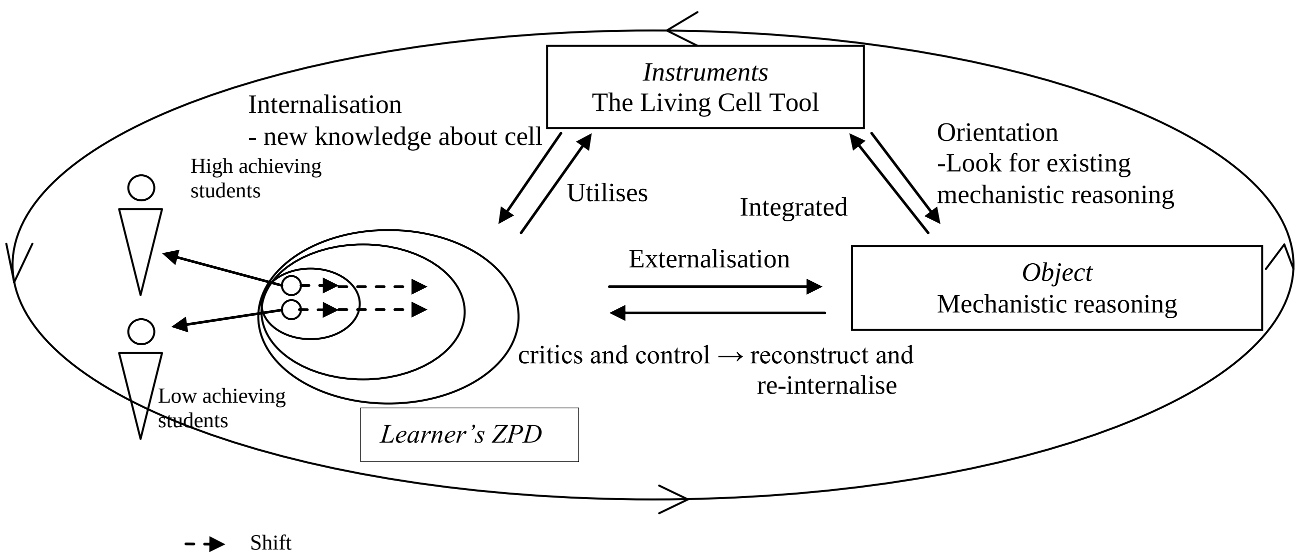

Figure 3.8. Steps in the Investigative Learning Theory in the study of mechanistic reasoning

Figure 3.9 shows an example where students learn about substances across the plasma membrane using Engeström's Investigative Learning Theory.

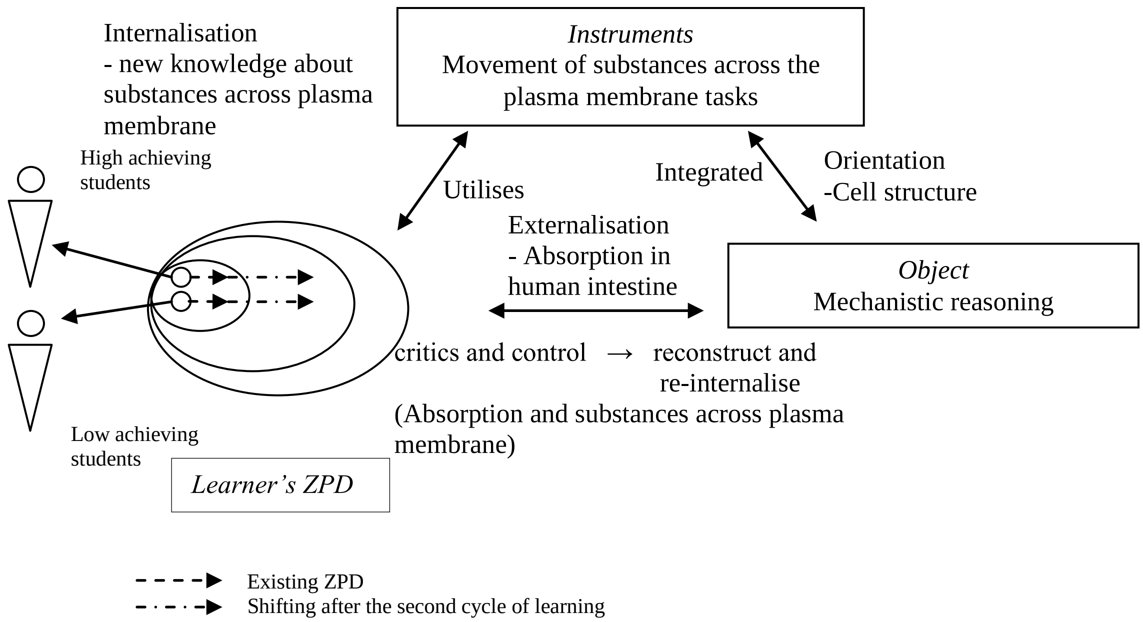

Figure 3.9. Steps in the Investigative Learning Theory in relating cell structure with the movement of substances across the plasma membrane

When a new topic begins, for example, the movement of substances across the plasma membrane is introduced, recalling students' prior knowledge is carried out (orientation), such as the structure and the function of plasma membrane that they have previously learnt in the cell structure component. At this point, high and low achieving students are believed to be at a certain ZPD. Internalisation takes place to relate the structure of plasma membrane to the movement of substances across the plasma membrane, for instance, diffusion and osmosis. During internalisation, the Living Cell Tool consists of several tasks to inculcate students' mechanistic reasoning so as to interrelate diffusion and osmosis with the membrane structure. Through internalisation, their zone of proximal development might shift if they can perceive the connection. Externalisation occurs after the implementing of newly acquired knowledge. For instance how substances move across the small intestines and are absorbed into blood capillaries. This is then followed by critique and control where students have to evaluate their own mechanistic reasoning that they have applied during externalisation. From critique and control, students can identify their mistakes and reconstruct their knowledge. Ultimately, students re-internalise the newly acquired mechanistic reasoning on how absorption occurs in the human body and how it is related to substances across the plasma membrane.

Internalisation and Re-internalisation

How information is processed and reconstructed in low and high achieving students' mind is crucial as mechanistic reasoning involves high cognitive processing. However, internalisation is not merely assimilating information to construct mental models. Newly acquired knowledge being rooted in one's mind engages several pathways before it can be substantial. Nonetheless, this is not illustrated in the Investigative Learning Theory. Hence, Craik and Lockhart's (1972) Level of Processing will be integrated to support this study.

Levels of Processing (1972)

Levels of processing proposed by Craik and Lockhart (1972) proposed that there are different ways to code materials being learnt and that memory codes are qualitatively different. The concept of a series or hierarchy of processing stages is often referred to as "depth of processing" (Craik & Lockhart, 1972, p.675).

The preliminary stage in the Levels of processing is concerned with the analysis of physical features such as when given a situation students will recognise the components or the process involved which takes place during internalisation. This input involves the sensory organs which are either audio or visual. The later stage is more concerned with matching the input against stored abstraction from the past learning which can be observed during externalisation. During the matching process in the preliminary stage, one is more interested in pattern recognition. Reed (1988) stated that the relation among pattern features is important in pattern recognition in order to proceed to a deeper cognitive analysis. For example, in learning the types of movement of substances transported across the plasma membrane such as osmosis, students will have to recognize the mechanism in the process and match the process with the features.

The deeper the processing, implies a greater semantic or cognitive analysis. Learning is insufficient with just recognising the patterns; it requires deep processing which involves much cognitive analysis. After the stimulus has been recognised, the newly developed knowledge can be further elaborated or enriched. For example in osmosis, after the link between process and the features, it may trigger associations, images or stories related to the process. Craik and Lockhart (1972) argued that elaboration or enrichment is not restricted to the verbal realm. In fact, they claimed that verbal rehearsal does not necessarily result in learning because if subjects do not attend to the meaning of words, they will only keep them active in short term memory. Therefore, if students keep repeating the definition of osmosis without comprehending the underlying concept, the information will only be kept in short term memory and might decay. This is aligned with Engeström's theory where he believed that learning is a mental and practical activity of the student which is much more complicated than mere "reception" and "storing". The knowledge acquired is meaningful to students if new knowledge and new tasks merge with the learner's activity and former knowledge. The weaker this connection, the less meaningful the matter is to the student and it is easier to be forgotten. As a result, students' ZPD might remain. By giving meaning to what the students are learning, it is essential for them to proceed to deep processing.

However, if retention is retained at one level of processing, for example the information is rehearsed many times, the information will be kept in short-term memory. This is known as Type I processing. When students keep repeating the definition and the process related to osmosis without understanding the holistic concept, it is considered as Type I processing as this can be done by just memorising the facts. Internalisation and re-internalisation into short –term memory might happen for a short period of time. Nonetheless, it might decay as new knowledge is not chained or linked to existing cognitive structures. Once attention is diverted, the information is lost.

Highly familiar and meaningful stimuli which are compatible with existing cognitive structures will be processed to a deeper level more rapidly and be better retained than less meaningful stimuli. The type II processing takes place at deeper levels where the subjects can make greater use of learned rules and past knowledge; thus, materials can be more efficiently handled and be better retained. Based on the working of type II processing as explained above, it can be argued that after elaboration and enrichment, students' mechanistic reasoning for the topic of movement across the plasma membrane will not be restricted to the process and the attributes of the process. The compartmentalisation of this information can only be maintained at a certain level. To proceed into a deeper level, students have to analyse connections between the structure of the plasma membrane and the movement across the plasma membrane. Reeds (1988) claimed that forming additional associations will help students in understanding information presented. By making semantic connections between the structure of the plasma membrane and the process, students would be able to deeply process the newly-acquired information which then can be internalised and re-internalised into long-term storage. The more the sematic connections constructed between the existing knowledge and the newly acquired knowledge, the more students' ZPD might be shifted. Figure 3.10 in page 85 shows an example of internalisation of the cell components and movement of substances across the plasma membrane as interpreted from the Theory Level of Processing (Craik and Lockhart, 1972).

As shown in Figure 3.10, students will receive a stimulus during externalisation (how glucose passes through the intestine into the blood capillaries) while using the Living Cell Tool. During this process, students have to recognise the process involved. For example, it can be simple diffusion or facilitated diffusion. Matching only occurs if students are able to identify the features of the process such as facilitated diffusion assists ion and large molecules to transport through the plasma membrane. Students are actually infusing mechanistic reasoning during pattern recognition and matching as mechanistic reasoning requires students to identify the entity and activity involved. Further elaboration is necessary to associate their existing knowledge with new information. For example, facilitated diffusion requires transport protein. The new knowledge gained will build upon the existing one so that the learning becomes meaningful. However, anchoring what they have learnt on certain topics and using it to externalise in a novel situation is inadequate. To proceed to type II processing (deep levels), relating previously learnt lessons such as the structure of the plasma membrane in the first chapter is necessary for the students to re-internalise the information into long term storage. Students, most of the time, are unable to transfer newly-acquired knowledge in a novel situation because their knowledge is retained in Type I processing and do not proceed to type II processing. Without semantic associatives, students' knowledge with regards to the Theory of Cell will always be compartmentalised. Re-internalisation into long term store will only be achieved with semantic association. Figure 3.11 shows the integration of all theories stated in this study.

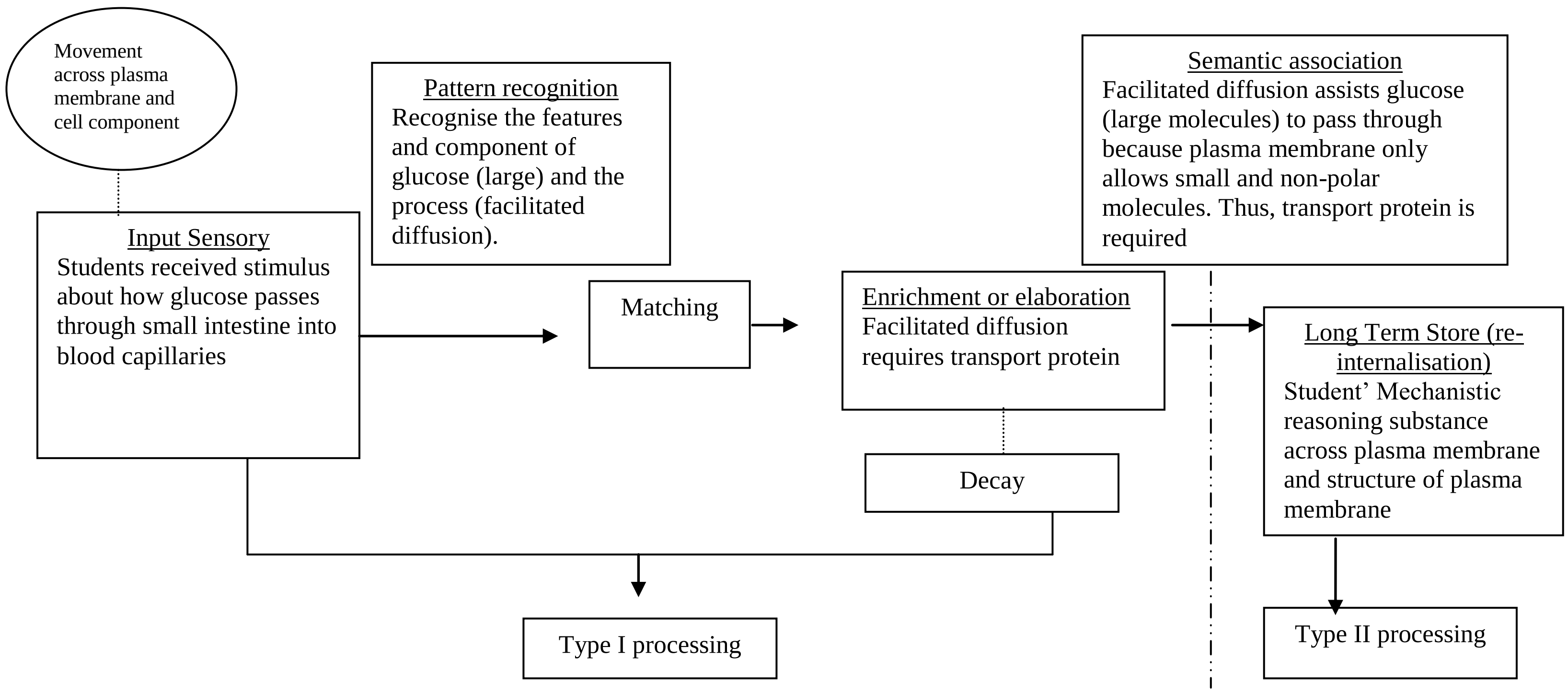

Figure 3.10. Students' internalisation and re-internalisation as interpreted in Levels of Processing (Craik and Lockhart, 1972)

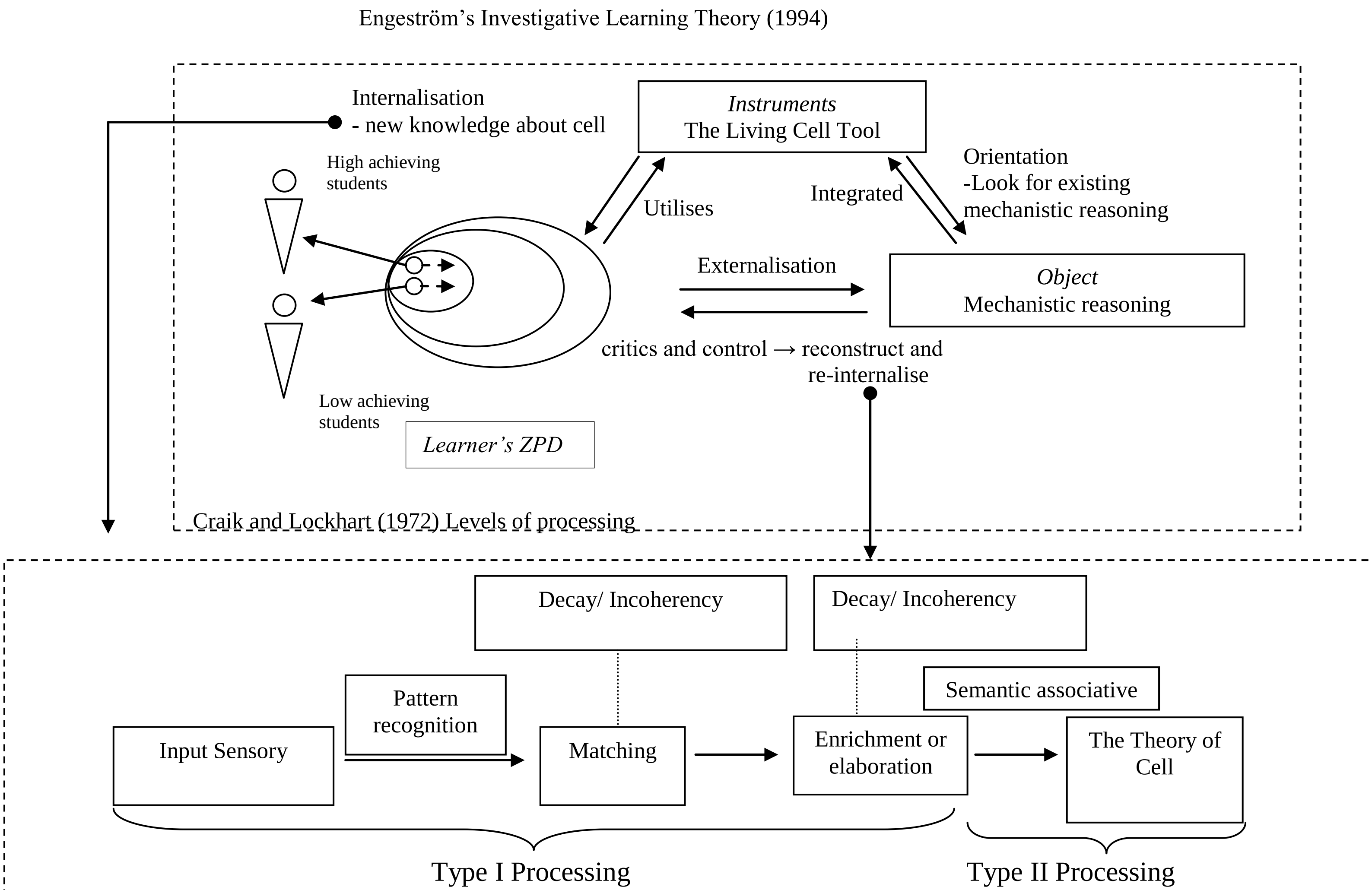

Figure 3.11. Students' Theory of Cell using the Living Cell Tool to infuse mechanistic reasoning as interpreted in Engeström's Investigative Learning Theory, Vygotsky's Zone of Proximal Development and Lockhart's (1972) Levels of Processing