Systems Thinking as a Teaching and Learning Tool for Biology Education

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Abstract

Biological research is moving towards a more holistic approach (systems biology) in an attempt to bring together the vast range of biological data to make more sense of living systems. This makes demands on scientists and teachers to draw together understandings from many areas of biological study and also to be literate in areas other than biology. It is important that the biology curriculum is modified to reflect this change and to ensure that coherent understanding for meaningful learning can arise.

This study aims to explore the ways by which systems thinking as an educational tool can enrich existing biology education practice. The specific aim was to develop systems-based educational material and to explore higher education students' reactions to this material and its impact on their learning processes.

The literature on systems biology and systems thinking is reviewed in the context of biology education. The work involved identifying areas of difficulty for first year undergraduates and establishing the views of experienced university teachers and researchers in Scotland about systems biology, systems thinking and biology education. This was followed by the development and application of the systems-based educational material in a selected topic in genetics. The material was later refined and used in Pakistan. The impact of the new material was assessed. The study also investigated the views of experienced academics applying and researching about the use of the concept of systems-thinking in biology education in the Netherlands.

The study showed that much of biology education is fragmented and that there are considerable difficulties with learning genetics stemming from its presentation as fragmented content. It also showed that there is widely held view that systems thinking should inform and could improve biology education. A framework based on the concept of systems thinking was used to develop systems-based educational material. This material was well received by first year university undergraduates and college students and made an impact on their learning.

Further work needs to be carried out on effectiveness in learning biology while further exploration of the use of systems-based educational principles for biology education is recommended. The study contributed significantly in offering a procedure for developing systems-based educational material.

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CHAPTER ONE

Introduction

1.1 Background of the Problem Investigated

The 20th century has seen many breakthroughs in the field of biology. Currently biology, and particularly genetics, is an exciting research field. Scientists are revealing many details of the molecular landscape of living organisms. Historically, a reductionist approach has been proved to be a successful way to gain knowledge about the living world. Biology has progressed rapidly and this approach is still important in the world of biology research. However, Capra (1997) has noted an obvious change of perspective in biology research practice which has taken place.

The need for bringing all the information together is being appreciated. Noble (2006) used the term *'Humpty-Dumpty'* for living organisms and stated that Humpty-Dumpty has been broken into billions of fragments, an impressive achievement. However, he also added that the time has come to put the Humpty-Dumpty together again and this is *systems biology*. Some people view it as a paradigm shift in biology (Katagiri, 2003; Raikhel & Coruzzi, 2003) while some believe it is the result of natural progress, growth of thinking, technology and need (Whitehead, 2007).

The first half of 21st century is described as the *"era of biology"* just like the first half of 20th century that was known to be the *"era of physics"* (Mesarovic, 2004). For a long time, biology research was an arena only for biologists. However, the trends are changing and now physical scientists, mathematicians, engineers and computer scientists have started working together with the biologists in putting these details together to build computer simulations (National Research Council, 2003; Abersold, Hood & Watts, 2000).

It has been reported that there should be a link between the research practice and the educational practice. When the research practice changes in a discipline, it demands a change in teaching of that subject with new tools, approaches and perhaps a new mind set (NRC, 2003).

King and Frick (1999) argue that educational practice has not changed much despite the industrial and digital revolutions which have changed society radically. Although this is simply not true, educational practice does tend to fall behind, not keeping pace with the changing trends (Zohar, 2004; King & Frick, 1999; O'Connor & McDermott, 1997).

It can be argued that the way biology is currently taught reflects the reductionist approach. Biology was, and perhaps still is, taught in a fragmented manner resulting very often in shallow learning. Different aspects of biology education have tended to lead to fragmentation, not developing coherent and meaningful understanding. Thus, in presenting biology as a body of knowledge, less attention has been devoted to connecting and linking information, levels of biological organisation and different concepts in biology (Verhoeff, 2003; Knipples, 2002).

The inherent complexity of biology has not been taken into account. Noble (2006) noted that our inclination has been towards ignoring complexity because it is uncomfortable. Hence, pedagogy distanced itself from complex reality (Chen & Stroup, 1993). Thus, for an understandable desire for simplicity, the underlying interconnectedness of different parts and ideas has been ignored. Fragmented educational practices have been reported resulting in mental pathways to reductionist thinking conditioned by decomposing and analysing (Cramer, 1993; Richmond, 1993).

A systems approach (systems-thinking) is influencing the research field and changing research practice in developing understanding of the biological world. The aim of research practice is to discover, know and understand the biological world. Similarly, pedagogical practice is to make known what is discovered and the aspiration behind it is to enhance students' understanding of the biological phenomena and concepts.

For deep understanding, knowledge has to be constructed (Johnstone,1999, 2000; Newton, 2000; Ausubel, Novak & Hanesian, 1978). Understanding does not flow intact from teacher to the learner and constructing knowledge and developing understanding is personal and requires considerable effort (Newton, 2000). Similarly, Nickerson (in Newton, 2000) views understanding as *'the connecting of facts, the relating of newly acquired information to what is already known, weaving the bits of knowledge into an integrated and cohesive whole'* (p.19). Therefore, he argues for the importance of establishing a relationship between ideas and concepts. This view of understanding is similar to what Ausubel et al. (1978) has expressed about superficial learning and meaningful learning. Hence, the ability to make links and connections of thoughts, ideas and information is a characteristic of understanding and understanding is an indication of quality of learning. There is evidence that people with true understanding have elaborate networks of information (Ausubel et al., 1978).

1.2 Education in Biology

In spite of pedagogical aspirations and efforts, science is still considered a difficult subject to understand by the students and a gap in students' understanding has been reported. Presently, pedagogy is blamed for shallow learning of students. There is truth in that to a certain extent but it is only partly true. Actually the difficulties of learning sciences have been related to the *nature of science* (the message) itself, the *method* by which science is traditionally taught (transmission system) and the *learner* (the receiver) to varying degrees (Johnstone, 1991). A brief description of these three elements will provide a background for emphasising the need to adopt systems-thinking approach in biology education.

1.2.1 Nature of the message

Biology is often thought of as an easy and 'soft' subject but biologists consider it a discipline of complexity. It deals with life which is a complex phenomenon in itself. The very objects of biology are living systems which are considered as systems of subsystems. Subsystems (part) form a larger system (whole). These systems are integrated both within and also in the surrounding environment in space and time, making hierarchies of levels of organisations. Thus, they represent an intense network of connections and links within and across the levels of biological organisation (Checkland, 1999; Capra, 1997). According to systems theory, natural wholes, organisms, are complex and composite consisting of a large number of interacting parts and these parts may be lesser wholes, such as cells in an organism (Boersma & Waarlo, 2003). Therefore, there is an endless display *of systems within the systems.* Everything is connected with every other thing. Put simply, sheer complexity pervades the natural world (Capra, 1997).

1.2.2 Nature of receiver

The human mind assimilates and processes information during the process of learning. There are many theories throwing light on different features contributing and affecting students' learning. However, the information processing model is an eclectic model (Johnstone, 1999; Johnstone, Sleet & Vianna 1994). This model talks about the nature of the information processing system and also depicts how the processing of information takes place.

Information processing models involve a *sensory memory*, a *working memory* and a *long-term memory.* The sensory memory (often described as a perception filter) selects the relevant information from the large amount of information, passing it to the working memory. The working memory is considered to be a shared space for both holding and processing information but is of fixed and limited capacity. Numerous studies (eg. Johnstone, 1991, 1997; Danili and Reid, 2004; Yuan, Steedle, Shavelson, Alonzo & Oppezzo, 2006) have reported a link between working memory capacity and students' performance in many areas of learning. Hence, it has been regarded as a rate-determining step in the learning process (Kirschner, Sweller & Clark, 2006). Long-term memory also has a significantly important role in the process of learning (Johnstone, 1991, 1992, 1997) and has also been described as a hub of connections (Newton, 2000) where ideas are linked and hierarchically arranged (Novak, 1984; Ausubel et al., 1978). In the long-term memory, storage of information can take place in different ways. The new information is either linked correctly, incorrectly, or remains unlinked (Johnstone, 1991, 1992, 1997). Hence, the mode of storage determines the level of understanding. In all the models of learning, there are implicit or explicit recognitions that learners can be constrained due to their own cognitive limitations. Apart from this it is also known that learners have a tendency to compartmentalise the knowledge (Kali, Orion & Eylon, 2003; Cook, 2006). This is understandable in that it makes learning less demanding.

1.2.3 Nature of the transmission method

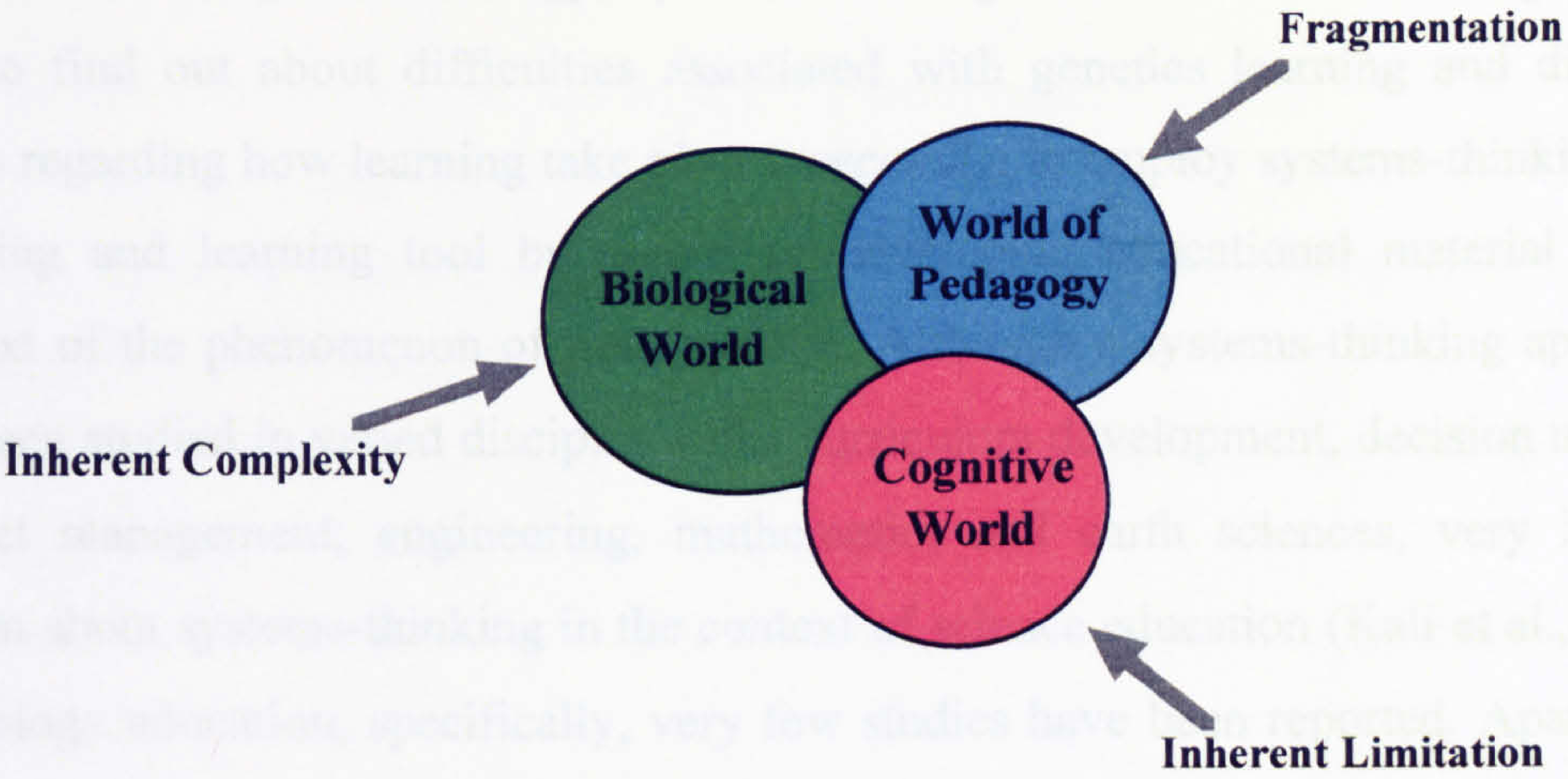
The transmission method (pedagogical practice) is a direct link between the message (subject content) and the receiver (learner) and, in biology education, it is often suggested that teaching tends to be fragmented (Verhoeff, 2003, Knipples, 2002, Gulyaev & Stonyer, 2002, Wilensky & Reisman, 2006). Scientific knowledge is not merely a list of factual knowledge; rather, it is an interconnected network of ideas and concepts (Johnstone, 2000). However, it appears that biology teaching emphasises one aspect of biological knowledge (imparting information), with emphasis on developing the links between knowledge being relatively neglected.

Teachers, being facilitators in the process of learning, have a responsibility to impart the biological knowledge the way it is. Hence, methods of teaching and availability of resources also have roles to play. In the academic world, to some extent the teacher is still a source of making the accumulated knowledge available to the learners. Unfortunately, the way the knowledge is acquired often leads to fragmentation.

Students are left to build their own links between the imparted and already existing knowledge unless there are deliberate efforts to emphasis and develop the links. Kali et al. (2003) and Cook (2006) show that students generally do not link the information spontaneously, and tend to compartmentalise it. Students may end up storing knowledge in compartments and the more compartmentalised it is, the less deep will be the overall understanding. One student may construct few connections and new learning is very poorly related to the existing knowledge. Another student may construct detailed, numerous and complex connections, integrated extensively with prior knowledge, achieving a very different level of understanding.

It can be said that in the process of learning biology three overlapping worlds are involved (figure 1.1). There is the sphere of the living world and its surroundings, the sphere of the world of pedagogy and the sphere of cognitive world of the learner's mind. Each world contributes in making biology difficult so that coherent and meaningful learning is not easy.

Figure 1.1 An Analogy: Three worlds involved in the process of learning biology



1.3 Statement of the Problem

The model in figure 1.1 illustrates the fundamental problem. Students studying biology have been reported developing shallow learning (tending to be memorised and unconnected) and it is possible to trace it to the three factors. Firstly, the biological world is highly complex; secondly, pedagogical practice tends to encourage fragmented learning and, thirdly, the cognitive world of the learner's mind face limitations in the form of a non-expandable working memory space and intrinsic difficulty in developing connections between ideas in long-term memory.

It is absolutely clear that the complexity of the natural world cannot be reduced if learner is to develop deep understanding (Chen and Stroup, 1993). Similarly, working memory space cannot be increased (Johnstone, 1997) and difficulty of making connections or the tendency to learn in compartments is also evident as a normal characteristic of learners (Kali et al., 2003; Cook, 2006). As neither the nature of the natural world nor the cognitive architecture of the learner can be altered, only pedagogy can be manipulated to bring hope for developing coherent understanding. Currently, it is being proposed to enrich biology education by using systems-thinking for developing better understanding: meaningful and coherent. However, it is not straightforward to apply systems-thinking as a pedagogical strategy (Kali et al., 2003).

1.4 Purpose Statement

The intention of the project is, *firstly*, to explore what has been reported in the literature about systems biology, systems-thinking and its educational importance, and to find out about difficulties associated with genetics learning and different views regarding how learning take places; *secondly*, to employ systems-thinking as a teaching and learning tool by means of developing educational material in the context of the phenomenon of transposition. Although a systems-thinking approach has been studied in varied disciplines like curriculum development, decision making, project management, engineering, mathematics and earth sciences, very little is known about systems-thinking in the context of science education (Kali et al., 2003). In biology education, specifically, very few studies have been reported. Apart from this, almost all the reported studies have been conducted with school pupils and there is a dearth of this kind of research with university students. Furthermore, most of the studies were aimed at enhancing, developing and measuring the systems-thinking ability (Kali et al.,2003; Assaraf & Orion, 2005; Ossimitz, 2000, 2001 & Klieme and Maichle, 1991,1994, both in Ossimitz, 2000) but very few studies used systems approach as a teaching tool (Verhoeff, 2003; Knipples, 2002). This is the objective of this project. *Thirdly,* the current project aims to explore the impact of systems-based educational material on students' opinion and attitudes, and the views of experts on educational and research practices and the use of systems-thinking in biology education.

As very little is known about the application of systems-thinking in biology education, the current study will serve as *a landmark for future research* in this area by defining the field of inquiry for further study. This study seeks to offer a *template* for developing systems-based educational material for the other difficult topics and formulate *systems-based educational principles* for biology education with the hope of enriching students' learning in a number of ways.

Although the current study does not aim to measure systems-thinking, it is possible that systems-thinking will be encouraged by its use in teaching materials. Cramer (1993) notes that pedagogy can set mental pathways. Hopefully, a systems-thinking pedagogy will contribute to make learners better systems thinkers.

1.5 Outline of Thesis

The current research study is presented in the following way.

- ♣ **Chapter two** reviews the paradigm shift, from reductionism to a systems view of life in biology research.
- ♣ **Chapter three** explores and presents the views about systems biology, its aims, challenges and its impacts on life.
- ♣ **Chapter four** explores different views about systems-thinking, its nature, its need, its implication and impacts in education.
- ♣ **Chapter five** presents the difficulties associated with biology teaching and learning.
- ♣ **Chapter six** presents different models of learning and the pedagogical insight they provide for biology education.
- ♣ **Chapter seven** describes the philosophical underpinning of the research design adopted for the current study and also the overall plan of the research project.
- ♣ **Chapter eight** describes the 1st phase of the research project, its methodology, findings and discussion.
- ♣ **Chapter nine** presents the 2nd phase of the project: the developmental of the systems-based educational material and its implementation and also the findings regarding students' opinion about the systems-based material and discussion.
- ♣ **Chapter ten** presents the 3rd and the last phase of the project, its findings of the interviews conducted with biology educationists and also discussion.
- ♣ **Chapter eleven** presents the findings and discussion regarding the effectiveness of the systems-based material used with biology students in Pakistan.
- ♣ **Chapter twelve** presents the detailed analysis of students' answers on a performance test; findings and discussion.
- ♣ **Chapter thirteen** brings together conclusions from three phases, answers the research question, states the limitations and contribution of the current study concluding with the recommendations for future research.

CHAPTER TWO

Changing Research Practice in Biology

This chapter presents a brief overview of the paradigm shift in science, changing research foci and practices in history of biology research, the place of reductionist approach in biology research and a shift of focus from mechanistic world view to systems view and characteristics of open system distinguishing the organisms from machine.

2.1. Paradigm Shift

The word paradigm has been derived from a Greek word 'paradeigma' which means 'pattern'. The term was made popular by Kuhn during the second half of 20th century (Hoban, 2002). Kuhn defined a scientific paradigm as "*a constellation of achievements-concepts, values, techniques, etc. - shared by a scientific community and used by that community to define legitimate problems and solutions* (Capra, 1997, p. 5). Similarly, Hoban (2002) views paradigm as a '*mindset* or a '*set of beliefs*' that has a great influence on thinking which in turn effects into action within a community.

Paradigm has been described as a change-enforcing drive. To show the influence of paradigm in terms of its moulding and defining power, Hoban (2002) equates it to a religion that permeates every aspect of life shaping and modifying communities. Although, history has witnessed its enormous power, Capra (1997) has argued that, in spite of its power, the attribute of permanence cannot be attached to it. It is dynamic. It keeps on changing and evolving and is like a shifting ground. This change of paradigm has been called '*paradigm shift*' by Khun (Capra, 1997).

Paradigm and paradigm shift is not only associated with scientific community (Capra, 1997). Society also goes through such shifts of thinking patterns. When a certain paradigm prevails or shifts, it influences the thinking pattern of individuals and guides their actions and practices such as selection of problems to be investigated and solutions to be found for a problem under consideration both in scientific as well as social communities.

Capra (1997) states that history has recorded paradigm shifts and that our world is at the edge of another shift. Katagiri (2003), Raikhel & Corruzi (2003) perceive the changing research practice as a paradigm shift while Richard (2007) believes that it is too early to call this change a paradigm shift. However, Whitehead (2007) describes this change as a result of a natural process of growth and development of technology and understanding about the organism and the knowledge accumulated. The following is a brief description of paradigm shift in the history of science.

The origin of modern science goes back to the rapid scientific development that took place in Europe between years 1500 and 1750 which is referred as the scientific revolution (Okasha, 2000). The historical background of Western mind set can be divided into three broad world views or paradigm: Christian world view, scientific or mechanistic world view and post-modern world view (Hoban, 2002). According to the Christian view (medieval world view); the universe was viewed as organic, living, and spiritual (Capra, 1997; Okasha, 2000; Hoban, 2002; Stacey, Griffin & Shaw, 2000). Truths about the world were described by authority, the church. This thought pattern dominated and prevailed until the sixteenth century (Hoban, 2002; Chalmers, 2000).

However, during the 16th and 17th centuries, a scientific revolution took place. Names associated with this revolution are Copernicus, Galileo, Descartes, Bacon and Newton (Capra, 1997; Okasha, 2000). Their discoveries jolted the foundation of the medieval world view. Analytical thinking was introduced to understand complex phenomena (Capra, 1997; Okasha, 2000). Rene Descrates said, '*If a problem is too complex to be solved at once, then break it up into problems that are small enough to be solved separately*' (Cramar, 1993, p. 167). He viewed the universe as a machine (deterministic world view) which could be predicted and understood completely by analysing (Cartesian method) its components (Capra, 1997). Living organisms were considered as machines but complicated involving complex chemical processes

(Capra, 1997; Hoban, 2002; Okasha, 2000). The mechanistic world view prevailed for a long time and, under its influence, science flourished and was established as a discipline explaining objective reality.

However, during the second half of 20th century a new paradigm called postmodernism emerged in contrast with the mechanistic paradigm (Hoban, 2002). This new paradigm has promoted 'pragmatic doubt' putting emphasis on the unpredictability and uncertainty of the world (Hoban, 2002; Midgley, 2000). Chaos and complexity theories began to use the new ideas of mathematics to show that what actually happens is unpredictable (Midgley, 2000). This world view which emerged in response to a mechanistic world view has been called an holistic, ecological world view (Capra, 1997).

Mechanistic and holistic world views are known under different names. The mechanistic world view is termed as reductionist, atomistic, and Cartesian method (Capra, 1997). However, Midgley (2000) makes a distinction between mechanism and reductionism. Mechanisim is *'a view that everything can be observed and described as if it is a machine - a predictable, functional, inherently understandable object seen from a discrete distance by an independent subject'* (2000, p. 2). Reductionism means *'looking for simple causal relationship between variables rather than trying to understand a wide range of interactions that can only be satisfactorily explained in terms of the functions of the whole systems'* (Midgely, 2000, p. 33). Both views treat an organism as something simply predictable. Different terms were used to put emphasis on understanding the whole, such as holistic, organismic, and ecological. The term which has become popular with reference to holistic approach since second half of twentieth century is known as 'systemic' approach. Analytical thinking was backing the mechanistic approach while 'systems-thinking is behind systems approach (Capra, 1997).

The mechanistic world view and the reductionist approach have enjoyed prevalence in isolation for a long time but perspectives are changing. The mechanistic world view has lost ground in biology; reductionism is still valuable but not in isolation (Midgley, 2000). A brief account of this paradigm shift in biology is now offered.

2.2 Biology and Paradigm Shift

Biology is an old science. Aristotle (384-322 BC) has been considered as the first biologist who conducted the systematic study of phenomena of life. His central work was entitled as '*The history of animals*'. For a long time, Biology was called '*Natural history*'. The term biology was coined in the year 1802. However, biology as a modern, mature and independent science emerged during the middle of 19th century between 1828 and 1866 (Verhoeff, 2003; Knipple, 2002; Mayer, 1997).

The nineteenth century saw many breakthroughs in biology. For example Darwin's '*On the Origin of Species*' greatly influenced the scientific community and shocked society because it appeared that he dethroned man as the highest creature and made him just a link in the process of evolution. Just like the Copernican revolution, Darwin's view initiated a revolution in the biological community. He created a new paradigm in biology. It was new because it did not fit into the established ideas and the way of thinking in the 19th century (Cramar, 1993; Okasha, 2000).

The formulation of cell theory, the beginning of modern embryology, the rise of microbiology and biochemistry, and the discovery of Mendel's laws of heredity are important discoveries and findings of 19th century (Mayer, 1997). With the formulation of cell theory, the attention of biologists shifted from the organisms to the cell. This shift led the biologists to explore within the cell boundary. Hence, it provided insight into the structure and functions of cell and many subunits of cell (Knipple, 2002; Capra, 1997; Cramar, 1993).

Later on, Weismann's, theory of germplasm made a distinction between germplasm and somatoplasm calling them immortal and mortal respectively: a concept deeply grounded in reductionism (Goodwin, 1994). Goodwin criticised that such distinction made the organisms just vehicles for the hereditary material. However, this breaking down of organism provided a ground for the foundation of a new field of enquiry in biology which came to be known as genetics (Goodwin, 1994).

The 20th century witnessed another revolution in biology. During the 1950s and 1960s, advancement in the field of genetics was the discovery of the physical structure of DNA, hailed as a super molecule (Okasha, 2000; Capra, 1997; Goodwin, 1994). With this achievement, a significant shift again took place. The researchers were now focused on the molecular structure of gene instead of cell. Biologists started believing that all biological functions could be computed from the information present in the genes: the *genetic programme* (Capra, 1997; Goodwin, 1994). However, Goodwin criticised the genetic programme by equating it to the old notion of *homunculus*: a miniature human being in every detail present in the germ cells. He viewed it as a new version of the old story (Goodwin, 1994).

These findings and discoveries reflect how the approach to study the phenomena of life has shifted from higher level of organisation to the lower levels in living organisms (from organism to cell and then gene). Over the years, cell biology underwent much splitting into new disciplines. Among these, the narrowest one is molecular biology: the study of certain classes of organic macromolecules (Rosenberg, 2002). Actually, the term '*molecular biology*' was coined in 1951 by Weiss and Astbury just to indicate the lowest level of investigation in the advancement of biological knowledge. Weiss (1969) stated that if the term molecular biology is applied as a deliberate self-limitation of the viewpoint, then it is one of the most spectacular advances in modern biology. However, it will be a misinterpretation of the term if this was seen as an attempt to explain all phenomena in living systems in terms of the molecular level. Goodwin (1994) argued that, in spite of this warning, the biologist moved from having an *organocentric* to a *genocentric* approach, claiming that the genes and their activities are enough to explain the properties of an organism. However, molecular biology flourished with a series of discoveries. The description of restriction enzymes and cloning were the major breakthroughs in 1970s which were the landmarks of genetic engineering and biotechnology (Westerhoff & Palsson, 2004).

Further research in the field of genetics and advancement in technology led the human genome project and accelerated a new method of research called 'discovery science' which enumerated the elements of a system without any hypothesis about the functioning of the system (Abersold, Hood & Walts, 2000). The human genome project was completed in year 2000. However, it was not the first genome to be sequenced. Before it, the genomes of many other organisms were sequenced. Currently, an enormous amount of information is flooding into the discipline of biology. Knowledge in the field of biology has expanded very rapidly, resulting in many disciplines in the domain of biology. In fact the foundation of modern science is based on a reductionist approach and this is now discussed in relation to biology.

2.3 Reductionism in Biology

While the mechanistic world view has largely gone from biology, the reductionist approach is still there. Hence, reductionism and holism are often mentioned in the literature regarding biology research. The term anti-reductionism is also referred as holism (Capra, 1997). Reductionism and anti-reductionism (holism) are often presented as two opposite poles, but, they are not as detached from each other as they are often presented. In fact they cannot be defined in isolation from each other. An unsteady balance between the two has been reported and, perhaps, holism and reductionism are inexorably coupled (Hull & Rgenmortel, 2002).

Hull (2002) classified reductionism in biology into two categories: *weak and strong reductionism*. The *weak reductionism* does not neglect the lowest level of investigation in biology but puts a strong emphasis on studying the upper levels of organisation as well. While, the claim of *strong reductionism* is that the only level worth studying is the lowest one. Strong reductionism claims that, when explanation is provided from the lower level, then higher level explanations do not add anything to understanding (Hull, 2002). Both types of reductionism have been observed in practice among scientists.

Certain beliefs or attributes are associated with reductionism and its counterpart in the case of biology research. Firstly, it is believed that the higher level properties can be determined from the properties of lower level (Regenmortel, 2002). However, it has also been argued that such a belief in lower level explanation disregards the complexity and emergent properties of biological systems (Holland cited in Regenmortel, 2002; Aderem, 2005). Secondly, the reductionists believe in linear causality while anti-reductionists go for the network or non linear causality (Regenmortel, 2002). Thirdly, reductionsists believe that every problem has a solution. Hard work and time is needed, though, to find the solution (Davies, 2005). They do not take into account the inpredictability of some phenomena. While anti-reductionists assert that some phenomena are too complicated to be understood in the light of reductionists methods, an understanding of such complicated phenomena, therefore, requires a holistic perspective (Hull, 2002).

Reductionism in biology research has been heavily criticised. However, in spite of this criticism, it is believed that biological knowledge has expanded because of a redutionsist approach (Barb, Julkowski, Swenson, Garrett, Shaw, & Young 1999). It has been found useful in biology in a host of accounts (Hull & Rgenmortel, 2002). Among the early works in the field of genetics, the reductionists way of thinking has played a very vital role in understanding the phenomena of hereditary. Mendel was successful because he employed the reductionist approach to his crossing experiments and discovered laws of hereditary. He started with a single contrasting character. Before him many people tried such experiments of crossing over but they failed because they worked with multivariate lines (Raikhel & Coruzzi, 2003). Similarly, due to the reductionist approach, cell biology has accumulated a large amount of information and knowledge about the structure and function of cell and organelles (Capra, 1997).

In spite of its contribution towards knowledge in the field of biology, the reductionist approach has some limitations and, hence, it needs the supplementation of holistic science (Hull & Rgenmortel, 2002; Raikhel & Coruzzi, 2003). It has been argued that reductionism needs to be put in a proper perspective and balance. Otherwise complexity of biological phenomena cannot be comprehended (Hull & Regenmortel, 2002).

Moreover, looking at the use of the term 'reductionism' in biology, it has been argued that there is no compatibility between the notion behind reductionism and biology research conducted at the lower levels of biological organisation. Katagiri (2003) argued that reductionism by its definition focuses on making something simple and manageable, avoiding complexity by discarding the extra information. It might be suitable for simple machines or closed systems but not for living organisms where nothing is extra. What is actually called extra is an attempt to gain simplicity of a situation and to avoid complexity (Katagiri, 2003).

Debru (2002) holds the same opinion that the idea behind reductionism was to make things simple for better understanding but this is not the case with biology. She argues that biological discoveries, focusing on individual components, are not moving towards simplicity. Every time in biological research when new elementary levels are revealed, they are even more complex than they were expected. Instead of simplicity, enormous complexity baffles the biologists. Thus, there is no compatibility behind the philosophical idea of reductionist approach and biological research in terms of simplicity.

Molecular biologists are often considered reductionist because of reducing the macroscopic system (biological property) to the structure and properties of microscopic elements (nucleic acid and protein) of the system (Richard, 1999). Biologists working with complex systems use molecular biology as a tool to unravel the complex processes of living organisms. They know that it is a reductionist approach and are also fully aware that knowledge of structure and function of macromolecules is not enough to understand the whole system (Richard, 1999).

Debru (2002) also argues that the word reductionism is often used to criticise molecular biologists. However, she claims that actually the word is most often used by the people who have no real idea of biology but that they use it for political, ideological and social reason having little scientific relevance. To her biology should be neither fully reductive nor non-reductive but it is both. Such a view is perceptive and sensible.

Debru (2002) suggests that the term reductionism is not appropriate for describing biology research. Reduction of physiological to molecular properties is not reductive at all because it is a reduction of complex to more complexes. Hence, she questions the need to keep this scholarly term alive because it is misleading and does not explain the proper working in biology. She sees this term as an *anti-science* because of its misrepresentation of science.

2.4 Departure from Reductionism

Reductionism as a strategy lasted for a long time and still exists; however, biologists in the 20th century started looking at living things differently. Hence, the concepts and ideas about organisms different from mechanistic world view and reductionism started emerging (Capra, 1997).

For example, the term 'morphology' came into usage to indicate the study of biological forms from a dynamic point of view. The view of nature as 'one great harmonious whole' was revived. This view lead some scientists of that period to see the earth as a living being, an integrated whole. Today this view is also the heart and soul of the modern and contemporary 'Gaia hypothesis' of James Lovelock (Capra, 1997). Similarly, the terms for organisms as being self-reproducing and being self-organising wholes also emerged. Later on, the problems of cell development and differentiation in the development of higher organisms jolted the foundations of reductionism and it resulted in the emergence of two schools of thoughts: *vitalisism* and *organicism.* They both recognised that the study of the parts alone was not enough for understanding the behaviour of the organism. However, they also had a contrasting view. The vitalists believe that a separate, non physical entity was required for the understanding of life. But the organismic biologists maintained that 'organizing relations' were essential for understanding life, not a vital force (Capra, 1997).

During the early twentieth century organismic biologists developed some concepts similar to contemporary systems-thinking. For instance, Ross Harrison explored the concept of organisation. The term "emergent properties" was coined for those properties which exist at a certain level of complexity but are not present at a lower level and the term 'system' was used for both living and social systems. Since then the integrated whole whose essential properties emerge from the relationship between its parts came to be known as a 'system' and from that time on, understanding of a phenomenon within the context of a large whole became 'systems-thinking' and biologists became pioneers in the field of systems-thinking (Capra,1997).

Overall, biologists began to see living organisms as complex systems rather than machines. Such systems could not be understood by reducing it to its components. The early concepts of some biologists about organism crystallised over the years and, later on, theories were developed about the working of systems. The focus of attention was shifting from parts to whole; from the interaction of sub systems to form a system and of systems to form a supra system. This shift led towards the origin of a systems view of living organisms and this is the theme of the next section.

2.5 A Shift from Machine to System

Having looked at the place and issues related to the mechanistic world view and reductionism in biology, this section presents a systems view of life focusing on the different concepts about the living organism, derived from systems theories.

Various conceptual constructs, metaphors or models for nature and living organisms appeared in each great period of science. The interpretation of every model has been reported as a reflection of the state of the prevailing techniques and machinery of the time (Bertalnaffy, 1973). For classical science, when only the mechanical machines existed, nature was like a clock; and the concept of '*animal as a machine*' was prevailed. Later on, in the nineteenth century, the period of industrial revolution, the steam engine and thermodynamics led the organism to be conceived as a '*heat engine*' and nature was an engine running down. Similarly, when the self-regulating machines like the thermostat and missiles of modern technology came into being, then organism came be known as '*cybernetic machine*' (Bertalanffy, 1973).

Organisms were mere machines until Bertalanffy, an organismic biologist who viewed the organism through a different lens. He took interest in the organism as a whole rather than its constituent parts (Checkland & Scholes, 1991; Capra, 1997; Hoban, 2002). He strongly believed that, in order to provide explanations for biological phenomena, it was necessary to adopt a new way of looking at life. Therefore, his vision was to replace the mechanistic foundations of science with a holistic science. He emphasised the difference between physical and biological science and took a very crucial step in recognizing living organisms as open systems (Capra, 1997). The distinction, he made between the biological and mechanical systems made a real difference in terms of developing understanding and treating biological systems differently from mechanical systems. Hence, the concept of organism shifted from machine to a system and a systems view of life emerged as a paradigm. A living organism has been defined as '*a system that maintains and even expands its ordered structures by constantly taking up external energy*' (Cramer, 1993, p.16). Thus, the living organism came to be known as a system rather than a machine.

System is either a physical entity (Bertalanffy) existing physically or it may be a personal or social construct to limit the investigation (Churchman, 1970 in Stacey et al., 2000) According to Bertalanffy, '*system is a set of elements standing in interrelations*' (1973, p. 55). To Checkland (1999), '*the concept systems embodies the idea of a set of elements connected together to form a whole, thus showing properties which are properties of the whole, rather than properties of its component parts*' (1999, p. 3). Similarly, Hoban (2002) views a system as an assembly of related elements that act together as an integrated whole. Sardar and Abrams (2004) view system as an entity that changes with the time. This is a more dynamic view of a system as it includes the element of time in the explanation of a system. Direction of time has been considered important in order to understand the biological processes (Cramer, 1993; Nicolis & Prigogine, 1977). Almost all these definitions and views present a system as a collection of deeply interrelated components.

Different types of systems have been described depending upon different parameters of a system. For example, *deterministic system*: if a system is predictable, stable and completely knowable; *indeterministic system* cannot be predicted (Sardar & Abrams, 2004). *Linear system* in which variables are simply and directly related; a *non-linear system* where variables are not directly related (Sardar & Abrams, 2004). An *isolated system* does not exchange energy and matter with its surrounding; a *closed system* exchanges energy but not matter with the outside environment while an *open system* exchanges energy, matter and information with environment (Nicolis & Prigogine, 1977). Kreymyanskiy (1981) divided the material systems: *unorganized systems* and *organized systems*. *Unorganized systems* are simple and the interconnection between the elements is uniform. The nature of elements does not change on leaving or entering the system; *organized systems* are regulated and varied, and deep-seated connections are present among the elements. Various terms are used for the living organisms: open, indeterministic, nonlinear and organized system. Different systems theories have presented different aspects of a living organism as a system.

Different scientists including biologists, chemists and physicists contributed different ideas or theories towards new understanding of life. They addressed different aspects of living organisms: structural organization, regulatory aspects and developmental and evolutionary aspects. These aspects defined and unfolded the characteristics of living system. Following is a historical development of some aspects of living organisms, studied by different scientists.

2.6 Structural Aspects of Living Systems

Bertalanffy (1973) presented a comprehensive theoretical framework, a General Systems Theory (GST), for describing living systems. It deals with the structural organization of the organisms. He, for the first time in history of biology, articulated the systems approach to study life (Capra, 1997; Verhoeff, 2003). The most important contribution of GST is the idea of open system and since then living organisms came to be known as open systems. Some of the structural aspects of living organism as a system are given below.

An **Open system** communicates with the outside world and exchanges material, information and energy (Bertalanffy, 1973; Capra, 1997; Vehoeff, 2003; Stacey et al., 2000; Midgley, 2000):

Interconnectedness: An open system does not stand alone in its environment. This connectedness is not just external but has penetrated the very nature of system and, therefore, exists inside of the system itself (Sardar & Abrams, 2004; Capra 1997).

Systems boundary: The boundary of a system ensures the identity of a system and its relationship with its environment to import and export the required material and is more or less permeable to maintain a continuous inflow and outflow (Bertalanffy, 1973; Cusins, 1994; Ossimitz, 2000; Stacey et al., 2000; Midgley, 2000).

Emergent properties: Behavior or the other properties of a system as a whole resulting from the co-operative activity of the components (Bertalanffy, 1973; Capra, 1997; Verhoeff, 2003; Stacey et al., 2000; Midgley, 2000).

Hierarchal order: The tendency to form a multi-leveled structure of systems within the system which is part of nested systems. A focused system can be a subsystem of another system (Bertalanffy, 1973; Midgley, 2000). Capra (1997) introduced the concept of network, the web of life for the nested system.

Steady state is the constancy of composition where the system remains constant as a whole in its macroscopic phases while there is a continuous flow of materials. In an open system, true equilibrium is not possible because it requires continuous supply of energy to keep itself at a distance from true equilibrium (Bertalanffy, 1973).

Progressive integration is a property of the living systems where its components become more dependent on the whole (Verhoeff, 2003; Bertalanffy, 1973).

Progressive differentiation is a property when the parts of a system become more specialized in their functioning (Verhoeff, 2003; Bertalanffy, 1973).

Progressive centralization is a phenomenon in which certain component takes up the leading role and thus dominates the behavior of the whole system (Verhoeff, 2003,; Bertalanffy, 1973).

Catabolism and anabolism in living system material involving substance being continuously broken down and regenerated for the purposes of building and energy production (Bertalanffy, 1973).

Equifinality is the achievement of the final state from different initial conditions and in different ways (Stacey et al., 2000). In open systems the initial conditions do not determine the final state. Its classical example is the experiments on embryos in early development. The same final state (the development of an individual sea urchin) can be developed from (a) a complete ovum, (b) from each half of a divided ovum (c) from the fusion product of two ova. Similarly, identical twins are the product of splitting of ovum (Bertalanffy, 1973).

2.7 Regulatory Aspects of Living Systems

Initially and formally, biologists did not address regulatory aspects but it was a group of engineers, mathematicians and social scientists and neuroscientists who were working on the patterns of communication. Wiener was a leading figure in this field and he named this new science as 'cybernetics', a science of control and communication in the animal and the machine. Wiener applied the theoretical concept of his theory, developed in the context of technical science, to biology as well. All the major achievements of cybernetics are grounded in making comparison between organism and machine (Capra, 1997). The regulatory functions that are the characteristics of a living system are given below.

Homeostasis: It is maintenance of balance in the living organisms. In a healthy organism, the internal environment remains constant when there is fluctuation in the outer environment. This constant maintenance of internal environment is called homeostasis (Capra, 1997; Stacey et al., 2000).

Feedback: Cybernetics introduced the idea of feedback and the feedback loop. It can be self-reinforcing (positive) feedback and self-balancing (negative) feedback (Capra, 1997; Stacey et al., 2000). A feedback loop is a circular connectedness of elements in a system which regulates of the entire system (Capra, 1997; Midgley, 2000). Cusins (1994) talks about internal feedback loops and external feedback loops. *Internal feedback loops* occur entirely within the system and are thought as a sub-system within the system; *external feedback loops* are the feedback information from outside the system. It is argued that the mechanism of feedback makes the system responsive (response-able) and flexible (Sardar & Abrams, 2004).

2.8 Developmental and Regulatory Aspects

During the second half of the 20th century, two developments (new mathematics of complexity and the concept of self-organization) contributed in further understanding of living systems. The idea of *self-organization* was implicit in the early discussions of cybernetics but explicitly developed in the second half of the century. Similarly, general systems theory while recognizing the emergence of complex behaviour of organization in a living organism explained this behaviour when non-linear mathematical and thermodynamics were used (Verhoeff, 2003; Capra, 1997). Some of the characteristics of open system from the perspective of its development and evolution are given below.

Order: Forrester (in Capra, 1997) introduced the concept of order. He coined a phrase '*order from noise*'. He asserts that, in self-organizing systems, order is created within the system. Systems takes energy from the rich material from its environment, integrates into its structure and increase internal order. Cramer (1993) calls it a dynamic order.

Self-organisation is a spontaneous emergence of new structures and new forms of behaviour in an open system (Capra 1997; Niclos & Prigogine, 1977). Open systems are able to create novel structure and new mode of behaviour if there is a continuous flow of energy (Sardar & Abrams, 2004).

***Dissipative structure*:** Prigogine described living systems in terms of a '*dissipative structure*' (Capra, 1997; Stacey et al., 2000). During 1960s, Prigogine developed a new non-linear thermodynamics to describe the self-organization of systems far from equilibrium. Classical thermodynamics describes '*equilibrium structures*' but non-linear thermodynamics introduced '*dissipative structure*'. The dissipative structures not only maintain their stability but also evolve when they face instability and transform themselves into new structures of increasing complexity. Classical thermodynamics states that dissipation of energy as a waste but Prigogine says that dissipation of energy brings order; hence, dissipation of energy is a source of order in living systems (Capra, 1997; Nicolis & Prigogine, 1977).

Autopoiesis: Maturana (in Capra, 1997) concentrated on the properties that should be inherent in a system to be called living. He concluded that circular organization is the basic organization of living systems. It means that a change in the interactive relationship between certain components will always change relationships between these components and certain other components. Later on, Maturana and Varela (in Capra, 1997) found a formal and complete description of circular organization in '*autopoiesis*'. This means self-making. They saw autopoiesis as a general pattern of organization common to all living organisms irrespective of their components. Autopoeisis is a network of production processes in which every component participates in the production and transformation of other components in the network. The entire network makes itself. Network is produced by its components and, in turn, produces its components as well (Capra, 1997; Midgley, 2000).

Boundary formation: Maturana and Varela further added to the autopoiesis by saying that autopoetic systems can limit themselves as a unit from their surrounding environment by creating and developing a boundary around the network of components. The boundary is created by the system itself due to the interacting activity of components and, therefore, is not imposed from outside. If a system has not got this ability is not a living system (Capra, 1997).

2.9 Bringing it Together

The living systems have been studied from three different perspectives and each perspective has highlighted the characteristics which makes them distinct from machines. These concepts are talked about as notions related to systems-thinking in biology. This brief account describes the shift of perspective from mechanism and reductionism in biology resulting in the emergence of systems-thinking.

Systems-thinking emerged simultaneously in three different fields: organismic biology, Gestalt psychology, and ecology. The ideas of organisimic biologists gave birth to a new thinking: systems-thinking. This takes into account connectedness, relationships and context. The key characteristic of systems-thinking is the shift from parts to whole, from objects to relationships, from measuring to mapping, from content to pattern, from analysis to synthesis. Thus, it is holistic, contextual and relational. Systems-thinking influenced engineering and management during the 1950s and 1960s. Its application to solve practical problems resulted in the emergence of new disciplines such as systems engineering, systems analysis, and systems management (Capra, 1997).

The next chapter explains the influence of systems-thinking in biology research.

CHAPTER THREE

Systems Biology

This chapter presents the application of systems-thinking to biology research. It includes the emergence of systems biology, different views about systems biology, its aims and challenges, its future implications and its impact on biology education.

3.1 Emergence of Systems Biology

Biology has passed through many revolutionary changes. These revolutionary changes were always accompanied by new technology and new ways of thinking. Similarly, Liu (2005) argued that the demarcations of scientific fields have always followed either a conceptual breakthrough or have been a result of profoundly enabling technology. The last revolutionary advance was driven by the application of technology in molecular biology. This advancement required the biologist to have a new approach called molecular thinking. Now biology is moving towards another revolutionary advancement driven by systems biology (Katagiri, 2003).

Although the terms 'systems biology' became popular recently, the concept of an integrated, systemic approach to the analysis of the cellular processes has often been employed by the engineers and scientists. However, the sequencing of genome and application of high technologies has revealed hundreds and thousands of molecules and has widened the view of the cell. Systems biology emerged as a term and a field to describe an approach that takes into account the genome scale and cell wide measurements to understand the biological processes and mechanisms (Stephanopoulos, Alper & Moxoley, 2004). Hence, systems biology originated with the expansion of molecular biology to genome-wide analysis. The emergence of this new field is regarded as a 'paradigm shift' for molecular biology which had focused on reductionist thinking (Westerhoff & Palsson, 2004). However, Westerhoff and Palsson (2004) reported that the foundation of systems biology has also been recognized as far back as the 19th century whole-organism embryology and network mathematics.

In addition to this, there is also an agreement that systems-thinking is the mind-set supporting systems biology. Its origin can be traced back to the 1940s when Bertalanaffy talked about it by defining biological systems as open systems. He believed that his theory would play a role in unifying various fragmented scientific disciplines. He did not, however, see the unification of different disciplines in his life time (Capra, 1997; Drug & Market Development, 2004; Friboulet & Thomas, 2005). Regarding the thinking behind molecular biology and systems biology, Westerhoff and Palsson (2004) comment that, "*systems-thinking differs from 'component thinking' and requires the development of new conceptual frameworks*" (p. 1251).

Traditionally, the cell was considered a system, highly complex but well organised. However, genome sequencing has opened a window to view a broad bio molecular landscape underlying cellular phenotype (Stephanopoulos, et al., 2004) and high-throughput technologies have made it possible to view the genome as a 'system to study. Hence, it has been suggested that the popular view of systems biology may be synonymous with 'genomic' biology (Westerhoff & Palsson, 2004). Westerhoff & Palsson, (2004) therefore argue that roots of systems biology lie first in the fundamental discoveries in molecular biology and, secondly, in the developments of recombinant and high-throughput technologies. Hence, these two lines of work are now merging in contemporary systems biology.

Regarding the emergence of systems biology, Kirschner (2005) has stated that scientific fields evolve just like species arise by descent with modification. At the outset, it is not easy to differentiate them from the already existing species and the sister fields because in the beginning they are just marginally different from them. It is only in retrospect that differences and founding events can be determined (Kirschner, 2005). It has been reported that the term 'systems biology' is not a very informative term and some have even argued that it is a fancy term for physiology (Mack, 2004). Bork (2005) has criticised biological terms by saying that the term *systems biology* remains fuzzy and indistinctive, like many biological terms. A naming committee was nominated to set the definition of molecular systems biology, a subfield/branch of systems biology (Liu, 2005). Liu (2005) says that definitions normally arise from a consensus of the scientific community. Apart from the criticism about the term *systems biology*, it has also been noted that there is no consensus about its definition yet. However, systems biology is no exception, the term *complexity* has also been reported lacking a unified theory and there are a number of definitions as well (Mikulecky, 2001).

The next section seeks to summarise various views about systems biology. There is no consensus view of a definition but an attempt is made to summarise the main perspectives in the literature.

3.2 Different Views about Systems Biology

The earliest definition of systems biology was, *the use of systems theory for explaining biological phenomena in terms of information and decision-making/control concepts ,i.e. the study of phenomena in terms of how the objects are related rather than what they are composed of'* (Mesarovic et al., 2004, p.19). This definition represents the theoretical framework of systems biology and a mind set to study the biological phenomenon.

Systems biology represents an analytical approach to the relationships among elements of a system, with the goal of understanding its emergent properties' (Hood & Perlmutter, p.1215). They further comment that systems may constitute anything from a few proteins, molecules, a complex molecular machine or cell to a group of cells executing a particular function. Therefore, systems analysis can be applicable to molecules, cells, organs, individuals or even eco-systems. Similarly, Westerhoff & Palsson (2004) regard the genome as a system.

Aderem (2005) states that, *Systems biology is a comprehensive quantitative analysis of the manner in which all the components of a biological system interact functionally over a period of time"* (p. 511). This talks about taking into account all the components of living organism (ranging from molecular to system level) which is the application of quantitative analysis to all levels of biological organisation. Similarly, according to Hood (in Mesrovic et al., 2004), '*Systems biology defines* *and analyses the interrelationship of all of the elements in a functioning system in order to understand how the system works'* (p.19). Similarly, Aebersold (2005) stated *systems biology is the study of the dynamic networks of interacting biological components'*

Kirschner (2005) gives a definition of systems biology:

> *'Systems biology is the study of the behaviour of complex biological organisation and processes in terms of the molecular constituents. It is built on molecular biology...physiology...developmental biology...evolutionary biology and ecology...Systems biology attempts all of this through quantitative measurement, modelling, reconstruction, and theory'* (p. 504).

This is a broader definition which embraces different aspects of a system. It talks about the intra-disciplinary and the inter-disciplinary nature of the field.To Westerhoff (in Henry & Washington, 2003), *It's different from physiology or holism, which studies the entire system. It's different from reductionist things like molecular biology, which only studies the molecule. It's the in-between".* He avoids two extremes, reductionism and holism, and finds a middle way. He seems to say that biology has shifted from reductionism but it is not holistic because it is extremely difficult to study the entire system. He also adds by saying that we are not going to study the entire system but the attempt is to try to take a *slightly bigger slice of a system.*

Similarly, Henry & Washington (2003) mentions some views about systems biology gathered from different researchers. These appear to be activity oriented as they express the specific tasks involved in systems biology. For example, systems biology *is a mathematical modelling of biological systems* (Schneider). Sauro considers systems biology as a three legged stool: experimentation, computation and theory. These three together make powerful tool for understanding systems. Lauffenburger views systems biology as *a combination of hypothesis-driven and discovery-driven research* (Henry & Washington, 2003). This statement expresses merging of two research approaches. Butcher, Berg and Kunkel (2004) has reported that the term systems biology encompasses many different approaches and models for understanding living organisms ranging from bacteria to man.

Russell and Furga (2005) present some views of biology by saying that to some people it is a *“dynamic and holistic consideration of data in systems context”.* Similarly, others define it *scale up of mathematical biology”.* It is quantification of biology which is a step towards reducing its soft and qualitative nature. To some, it is collaboration between biology and engineering so is interdisciplinary where biology has to go hand in hand with hard sciences.

Mack (2004) argues that, *a systems approach is designed to integrate and analyse varying streams of biochemical information in ways that are not obvious to even the highest of human intelligence...’* (p. 1223). This description takes into account explicitly the human mind limitations. Thus, systems biology is a tool to expand the human intelligence, where it is limited, through the use of technology. It is believed that human minds are not capable of drawing inferences about the emergent properties of a system from a massive amount of information. However, it is possible to intelligently interpret an enormous amount of visual information. Therefore, systems biology is also an answer to human limitations of dealing with huge information flooding biology due to the interaction between biology and technology (Aderem, 2005).

All these views are not exclusive but they provide information of the field from different angles. The following is a summary of views about systems biology.

What is systems biology?

- Theoretical frame work to study a system
- Analytical approach
- Quantitative measurement and analysis
- Modelling approach
- Interdisciplinary and intra-disciplinary
- Combination of approaches
- Expansion of human intelligence

However, the various statements and approaches all express the same core idea which is an interest in understanding a system in a holistic way and a way of analysing the data such that it can be quantified and digitalised for developing computer models. It is an interdisciplinary field where an analysis of relationship and non linear causality is the key tenet.

The systems approach has been has been described as an old approach under a new title (Adrem, 2005; Bork, 2005; Henry & Wahington, 2003; Friboulet & Thomas, 2005; Mesarovic et al., 2004). However, what is novel is the renewed interest in it which has led to its development as a new field (Friboulet & Thomas (2005). Abersold et al. (2000) has mentioned a number of terms which have been listed to describe systems biology such as comprehensive biology, post genomic biology, quantitative biology, mathematical modelling of biological processes, multidisciplinary biology, molecular physiology, the convergence of biology and computer science, and more. These terms do not describe systems biology as new.

Mesarovic et al. (2004) view systems biology as a new term for the rebirth of a previously existing approach. They believe that systems biology was reborn out of necessity in the post-genome era. When it was realised and felt important to know how the components interact to result in the observed behaviour of the system: a shift from reductionism to a holistic perspective (Mesarovic et al., 2004). Aebersold, Hood &Watts (2000) view the emergence of systems biology as a result of discovery science. The availability of enormous data raised the problems of storing, interpreting and publishing the data because of the inability of the traditional methods to cope. Therefore, dependence of biologists on computational tools gave birth to a new approach to biology: an interaction between biology and technology which caused the emergence of systems biology.

It could be argued that the systems approach was already in operation in biology but with the less involvement of sophisticated technology which has not been available in the past (Aderem, 2005; Bork, 2005). Biologists always carried out analysis keeping in view the system. However, tools like mathematics and computational skills were not very strong in the community of biologists. As they have developed these tools and skills, they are, therefore, seeking to reach a level of understanding about a system where prediction, control and design are feasible (Henry &Washington, 2003). The fast pace of technological development during the 1980s contributed towards the emergence of systems biology as a discipline where a systems approach was in operation with the sophistications of technology (Aderem, 2005; Bork, 2005). The interaction between biology and technology is an open acceptance and declaration from biologists, that comprehending living systems is a difficult task without technological help (Friboulet & Thomas, 2005).

It has been stated that systems biology has two segments: (a) a data driven segment and (b) computational segment. The former segment of systems biology is still dominated by the classical biologist with its aim of acquisition of detailed and elaborated knowledge about the description and function of each component. This approach (reductionism) was strongly promoted by molecular biologists that attributed biological phenomena to the action of one or a few genes. However, in contrast to conventional reductionism, systems biology introduces high-throughput reductionism which involves a 'top-down approach' and a 'bottom- up approach' (Drug and Market Development, 2004). The top-down approach is to decompose the system into smaller parts but the bottom-up approach reconstitutes the elemental into larger wholes. The top-down approach appears to be similar to the reductionist approach but they differ in their emphasis. The reductionist approach attributes the biological phenomenon to the action of genes (linear causation) but the 'top-down' approach considers the whole system with its full complexity and interconnectedness (non-linear causality) for the description of any biological phenomenon (Katagiri, 2003). Hammer, Sinclair, Chapman, & Oosterom (2004, citing Sinclair and Horie, 1998; Snap, 2001; Katagiri, 2003) place emphasis on a linkage between top-down and bottom-up approaches calling it a dialectic approach. This forward and reverse approach has been reported as a link between two worlds, the world of molecular biologist and the world of whole-physiologist.

The second segment is the computational segment of systems biology which involves computer scientists, mathematicians, and engineers. Its focus is at constructing mathematical models. They are expected to be helpful in developing a hypothesis about the behaviour of systems after making some perturbations. These predicted effects of perturbation then can be tested in silico (experiments performed on computer), and then in vitro and vivo experiments. Although it all seems very fascinating, computational systems biology is in its infancy (Kitano, 2002) and many promising programmes are still at the planning or early implementation stages (Research and Market Development, 2004). Biology is at the crossroads of developing understanding and facing a crisis and challenges (Mesarovic et al., 2004).

Thus, overall, the term 'systems biology' may be new but the systems approach is not new. However, the integration of biology and technology on a large scale is a new development while biologists and scientists from other disciplines rarely had an opportunity to interact in studying the phenomenon of life.

3.3 Aims of Systems Biology

Systems biology seeks to explain complex biological phenomena taking into account the net interaction of cellular and biochemical components within a cell or organism (Liu, 2005; Aloy & Russell, 2005). Its aim is to provide an explanation about the properties and behaviour of the biological system through the integration of information; to make accurate and quantitative predictions about the behaviour of the system; to predict the effect of the modification on the systems is the goal of systems biology. The simulation of the behaviour of systems is the expectation of systems biology (Katagiri, 2003). It is expected that once more accurate models are developed, biologists will be able to accomplish two tasks which are beyond the reach of traditional biology: firstly, to predict the behaviour of the systems in the face of any induced change or perturbation; secondly, to induce change to create new emergent systems properties (Aderem, 2005).

Aderem (2005, p.513), referring to the key work of the Institute of Systems Biology in Seattle, emphasises integration:

> *'Integration of the various technologies, integration of the various hierarchical levels of biological information, integration of biology and technology, integration of crossdisciplinary scientists, integration of industry and academia and finally, integration of discovery and hypothesis driven science'*

It is being realised that there is a need to have collaboration between technology-focused scientists and biology-centric investigators to address the fundamental biological questions (Liu, 2005). However, biology is many decades away from achieving anything like these goals (Aloy & Russell, 2005). Even the human genome project that seemed to be quite laborious and demanding becomes a small project by comparison. However, systems biology is just at the initial stages and has many demands and requirements to get going.

3.4 Challenges of Systems Biology

Some challenges have been mentioned in the literature (Katagiri, 2003; Liu, 2005 Mesarovic et al., 2004; Aderem, 2005; Research and Market Development, 2004; Hood in Henry & Washington, 2003). These issues and challenges can be summarised:

Issues and Challenges

- Data handling issues
- Need of conceptual frame work
- Interdisciplinary research teams
- Training of new generation of systems biologists
- Acquiring new technological capability

All these needs and challenges are important for the success and progress of systems biology:

(a) High quality data is needed because if data is not of sufficient quality, then it will be a problem for systems biology practice (Katagiri, 2003); time, money and collective efforts are greatly needed for acquiring high quality data (Aderem, 2005);

(b) There is a need to put data set into digital format (digitalise biological output) in such a way that it can be computed;

(c) Computational power is needed to analyse the massive amount of data;

(d) The capacity to integrate heterogeneous data into usable knowledge format needs to be developed (Liu, 2005);

(e) A conceptual frame work is also needed for systems biology research. It is argued that although mathematical or computer models are important, investigations should go beyond building such models because biological phenomena cannot be predicted with great precision (compared to classical physics). Therefore, non-numerical mathematical tools are needed for explanation. It is important to search for organising principles rather than only concentrating on predictive description that is modelling (Mesarovic et al., 2004);

(f) The most important need is to have an interdisciplinary team of researchers who are also able to develop the required technologies and computational tools. The need for new technology and tools has to be dictated or suggested by biology. In other words, biology drives technology and computation and in turn gets revolutionised by them (Aderem, 2005);

(g) A new generation of researchers needs to be trained with emphasis on their core discipline and in the complementary computing skills (Research and Market Development, 2004). Similarly, Hood (in Henry & Washington, 2003) believes that future scientists have to be literate in multiple subjects like computer science, applied mathematics or engineering. Similarly, it has been reported that biologists are depending upon technology but current technological capability is a limiting factor. Similarly, making biology predictive is a challenge (Liu, 2005).

It has to be admitted that the requirements are daunting. Biological knowledge has expanded at a great rate. The idea that biologists have to add a range of extra skills may seem impossible. Teamwork of specialists able to communicate and collaborate might be the better way forward but even this faces problems. The present organisational/ departmental structure of many universities does not support such team work. Biologists, engineers and computer scientists work in their own compartments interacting rarely (Liu, 2005; Aderem, 2005). However things are not completely hopeless. Institutes of systems biology are being established in different universities. Joint collaboration between a biology-focused and technology-oriented investigator may pave the path for systems biology projects: interdisciplinary research (Liu, 2005). A statement published by Manchester University in an advertisement to recruit a chair in systems biology provides a wide scope of systems biology:

> *'Systems Biology is a focus of our interdisciplinary activities. The scientific strategy focuses on Biocatalysis, Biomathematics and Biocomputing, Biomoelcular and Cellular Analysis, Biophotonic and Bioelectronics, Biomolecular structure and Dynamics, Biotechonology and Systems Biology'*
>
> (Friboulet & Thomas, 2005, p. 2405).

This shows that systems biology has many facets and many scientists from a variety of disciplines are required to make it a cross-disciplinary field.

Similarly academics are sometimes reluctant to work in teams. Aderem (2005) has noted various reasons for this. Individual contributions in research fields are often important in departmental promotion and advancement in universities. Liu (2005) suggests that individual efforts need to be judged in the light of broad aims: its contribution towards the advancement of collective projects.

Another hindrance is the way funding arises. Liu (2005) argues that grants are often administered in such a way that advances by the individual scientists are rewarded. Similarly, traditionally, funding committees are reluctant to grant money for new approaches and risky projects (Aderem, 2005). Similarly, Aderem (2005) also notes that access to technology is a challenge for universities in the practice of systems biology. In addition to this, there is a challenge inherent and embedded in the nature of biological systems. It is the sheer complexity that baffles biologists and, therefore, it is important to take into account the immense complexity while studying and working on living systems (Mesarovic et al., 2004). However, despite all the challenges and requirements systems biology is nonetheless becoming a trendy science and is attracting a lot of attention.

3.5 Future Implications

It is expected that almost all areas of life where biology is involved will become influenced by the progress in systems biology. The impact of systems biology will be theoretical as well as practical (Kitano, 2002). The following is a summary of the areas of impact gathered from the literature and each is discussed below:

- **Theoretical impact**
- Coherent understanding (systems-level understanding)

Practical impact
- To design desired biological systems (biotechnology)
- To provide preventive and predictive medicine (pharmaceutics)
- To improve crop quality (agriculture)
- To clean up environment

From a theoretical perspective, ways of gaining knowledge and developing system-level understanding about the structure and dynamics of native biological systems (animals, plants and micro organisms) will have an impact (Friboulet & Thomas, 2005; Voigt, 2004). Kitano (2002) stated '*there is now golden opportunity for systems-level analysis to be grounded in molecular level understanding, resulting in a continuous spectrum of knowledge*' (p, 1662). While the practical aspect will have an impact in agriculture, medical practice, pharmacy and environment (Voigt, 2004), it will also impact biotechnology in designing biological systems with desired properties that do not exist in nature (Friboulet, & Thomas, 2005). In the field of pharmaceutics and medicine, the systems biology researcher views bacteria as living machines which can be modified genetically to develop desired characteristics and properties to perform a variety of jobs such as cleaning up toxic chemicals, seeking out and then attacking cancer cells: hence these living machines will act as cleaner as well as fighters (Voigt, 2004).

The impact of systems biology will be in developing an understanding of pathology and malfunctioning for controlling the state from the cell to the whole body. It will provide therapeutic targets for treatment of diseases. It is argued that systems biology will revolutionize the practice of medicine in terms of predictive and preventive medicine (Aderem, 2005; Friboulet & Thomas, 2005). Many pharmaceutical companies specialising in systems biology are building computational models. Henry & Washington (2003, citing Hill) says that these computer simulations will be used to test the drugs on computer (digital patient) before they are tested on animals or in clinical trials.

Similarly, plant systems biology is a nascent field and there are significant efforts in this field also to develop the whole plant modelling or "in silico plant". It holds promise for crop improvement (Raikhel & Coruzzi, 2003).

3.6 Systems Biology and Biology Education

Biological research is being transformed. This change can be seen in a number of ways. Firstly, biological concepts, models and theories are becoming quantitative. Secondly, the connections between life sciences and physical sciences (chemistry and physics, and mathematics and engineering) are becoming deeper. Hence, biology is becoming more dependent on these sciences. The way of designing, performing, and analysing experiments is rapidly changing; computers play a central role in the acquisition, storage, analysis, interpretation, and visualisation of enormous quantities of biological data; new kinds of scientific communities are emerging; due to the advancement of rapid exchange of information, the ways in which biologists communicate and interact are undergoing rapid transformation (NRC, 2003). A recent report of American Cancer Society (in NRC,2003) stated *In the post genomic era of research, multidisciplinary and interdisciplinary research will command centre stage, requiring team approaches and the collaboration of many individuals from vastly different fields...* " (p. 12).

The collaborative research is asking something more from the new generation of biologists which once was not an essential prerequisite. However, it has been realised that contrary to this change in biology research and its demands for new skills and thinking, biology education has changed relatively little. A report by American Cancer Society (In NRC, 2003) indicates *The changing paradigm of research calls for innovation and changes in the education of scientists along the spectrum of k-12, undergraduates and graduates education* (p12).

It is suggested that there should be some kind of compatibility between the research field and biology education; otherwise developing academics will not be comfortable working in research fields. It is argued that there is need in biology education to expose future biologists to a more interdisciplinary curriculum. This exposure will enhance collaboration among peers from different scientific disciplines. In many universities these subjects, physical sciences and mathematics, are studied and taught in parallel but they are not integrated and meshed with biology courses (NRC, 2003). This is a demanding suggestion and may prove difficult. With the rapidly increasing range of knowledge and the time pressures on curricula, it is difficult to see how more subject matter can be incorporated. Perhaps what is needed is a change in a paradigm of thought rather than an increase in what is taught.

It is important to make biology integrated by teaching other disciplines with deep connections to biology research. It has been suggested in NRC (2003) that an interdisciplinary curriculum will attract those students to biology who are strong in quantitative skills and find biology a soft subject. All students studying biology will not have an equal interest in mathematics but its inclusion will help to identify the importance and relevance of quantitative science in addressing the life science questions. Although curricular aspects (interdisciplinary content) are important to meet the challenges of the future, it is essential to pay attention to the pedagogical aspects (how it is taught) of biology education. Coherent understanding of the biological concepts is essential. So the way biological knowledge is presented is important. This chapter has presented the application of systems-thinking in biology research (systems biology). The next chapter presents the need for systems-thinking in educational sphere.

Wiess (1969), in an analogy, drew picture of a painter and scientist working on minute details on a canvas and natural biological system respectively. He emphasised the periodical stepping back to know the progress made by viewing the whole picture. In his own words, *only by such shuttling back and forth between the worm's eye view of detail and bird's eye view of the total scenery of science can the scientists gain and retain a sense of perspective and proportion'* (Weiss, 1969, p. 3). The emergence of systems approach can be equated to stepping-back to see the whole big picture.

CHAPTER FOUR

Systems-thinking in Education

The previous chapter described the application of the notion of systems-thinking in biology research. This chapter explains the need for systems-thinking, its definitions and its application in biology education.

4.1 Thinking, Education and Changing World

Thinking and control of thinking is a characteristic of human capability. It is an inherent capacity that differentiates man from the rest of the living world and also from highly sophisticated computers. It would not be an exaggeration to say that human survival depends upon thinking. Being frail creatures in a hostile environment, humans had to learn to use their maximum cognitive capacity for their survival (Fisher, 1992). Doing and thinking are said to be connected so there is no doing without thinking. Although thinking is a very personal activity, it is not done in isolation; rather it takes place in a social context. Therefore, it can be taught and learned, and from this belief stems the idea of teaching the thinking skills (Fisher, 1992). School has been an important formal institution not just for imparting knowledge but also as a social context for shaping thinking. Cramer (1993) argues that thinking patterns and pedagogical practices are intertwined: pedagogy sets the mental pathways. Hence, a thinking pattern is a reflection of the nature of pedagogy and the nature of pedagogy is the prediction of its outcome, the thinking pattern.

Fisher (1992) adds that pedagogy itself is influenced by learning models. In the past, learning models emphasised simple forms of learning and focused on improving the teaching of basic skills; thus pedagogy drawing from these models focused on teaching the basic skills. Previous studies investigated the learning and learning processes. However, there is now some consideration about how to teach about the complex systems (Lesh, 2006) and how people learn to think systemically? (Sweeny & Sterman, 2001) and what are the issues related to the learning and teaching of complex systems (Jacobson & Wilensky, 2006). Fisher (1992) argues that the present age is not an age of simplicity. The role of the school has to go further and the focus has to be shifted from simplicity to complexity. The current learning models talk about learning processes and developing autonomous ways of learning. The reason behind this shift is that the view about children, school and society has changed (Fisher, 1992).

An awareness of societal change has perhaps stimulated the teaching of thinking skills. It has been argued that thinking skills need improvement and supplementation (Checkland & Scholes, 1990; Richmond, 1993). The world is changing so rapidly that it is not enough to teach just the factual knowledge in school because it is difficult to assess what knowledge will be appropriate in future beyond the school boundary (Fisher, 1992). Therefore, it appears imperative to equip children with skills that can be helpful in controlling their lives and their own learning because there will be no end of this learning process (Fisher, 1992; Smith, 2003).

King and Frick (1999) suggest that society needs manipulators, synthesisers and creators of knowledge. Similarly, Checkland and Scholes (1990) argue that managers are needed to solve problems. They view every single individual as a manger on a small scale. They use the terms *'manager'* and *'managing'* in broad sense. To manage means to deal with the flux of interacting events and ideas which unroll through time and the manager is a person who tries to improve the situation which seems to be problematic. However, they also argue that today's solution becomes tomorrow's problem. Hence, problems cannot be solved once for all. Therefore, it has been realised that instead of solving problems for the learners and society, the need is to provide them with tools for finding solutions for themselves. In this way, they can survive in the complex world and be lifelong learners, managers, manipulators, synthesisers, and creators of knowledge.

Richmond (1994) also holds a similar opinion by saying that our world is rapidly changing and every age has its own problems, different from the previous one. Therefore, the mindset has to be changed to meet these needs. Intellectual tools have to be polished and renewed for survival. There is some suggestion that the intellectual tool for this age is systems-thinking although there are different names for this type of thinking: systems approach, systems dynamics, systems model and systems (Richmond, 1994); contextual thinking, ecological thinking, network thinking (Capra, 1997). Scheetz (in Senge et al., 2000, p. 231) argues that, *"systems-thinking has been around forever."* However, a question arises here: *why do we need systems-thinking now more than ever?*

4.2 Need of Systems-thinking

Richmond (1994) argues that systems-thinking is needed because communities are becoming more complex and interdependent; this interdependency weaves all of us into a web of interconnections and assigns a new title of *web-mate* to us. This increasing interdependency demands a new way of learning and thinking (Richmond, 1994). Similarly, Senge (1990) argues that this is the first time in history that man has the capacity to create more information than anyone can absorb and interdependency has become far greater than one can manage. Therefore, he also advocates the need of systems-thinking. O'Connor and McDermott (1997) also hold the same opinion by saying that the world has become so interdependent that distant events disturb lives. For example, the tension in the Middle East is manifested in the local garage as an increase in the price of petrol. Hogan and Weathers (2003) also express the same views about the need of systems-thinking.

Similarly, Forester (in Senge et al., 2000) asserts that, if people do not understand the systems they are working with, it means they do not understand interconnectedness and interdependence. He argues that lack of such understanding can be addressed but it requires much time and he thinks that it should be preferably dealt with at an early age. He sees this in terms of teaching practice. Richmond (1991) blames pedagogy for developing a focus on analytical thinking, while Forester (in Senge et al., 2000) demands that pedagogy should bring change for thinking in a systems way (systems-thinking).

The problem is that the way teachers teach is influenced most strongly by the demands of the education system. Where the system places value on the correct recall and application of information and procedures, teachers will aim at these. This is often beyond the control of the individual teacher or even the school.

Apart from the social needs, educationists also advocate the need of systems-thinking to deal with students' incoherent understanding, the fragmented nature of teaching, the curriculum and assessment practice (Knipples, 2002, Knipples, Waarlo, & Boersma, 2005; Verhoeff, 2003; Hoban, 2002). A considerable amount of research supports the claim that learning occurs in compartments (Linn et al., in Kali at el., 2003) and that if information is presented to the students in isolation; it is very rare that they integrate it spontaneously (Songer & Linn in Kali at el., 2003). Particularly in biology education, the need of systems-thinking has been highlighted (Knipples, 2002; Verhoeff, 2003; Smith, 2003) because biology deals with complex systems.

Scientists can be seen to be expanding their thinking capacity (systems-thinking), through collaborative and interdisciplinary approaches (Hogan & Weathers, 2003). For researchers, these are considered as tools for analysing complex biological content; for teachers and curriculum developers systems-thinking is profitable in sequencing and arranging the biological content: for students studying biology, it is a desired learning outcome. The need of systems-thinking has become a slogan in many areas of research, education and society (Boersma & Waarlo, 2003). However, it is important to see how systems-thinking is seen and this is the theme of the next section.

4.3 Defining Systems-thinking

The phrase normally associated with systems-thinking was around since the time of Aristotle when he said *'the whole is greater than the sum of its parts'* (Chen & Stroup, 1993, p. 449) but at this time was not known as systems-thinking. Its modern origin is traced back to Bertalanffy who also never used this term.

The term 'systems-thinking' was coined by Berry Richmond in 1986 to introduce the driving force behind his STELLA software. Before this he used the term 'structural thinking', the term used by the civil engineers. Since 1986 the term ' systems-thinking' has been widely used (Richmond, 1994, Ossimitiz, 2000, 2001). In spite of its wide use there is no concise definition. Neverthless the mind set behind every definition is similar: to develop comprehensive understanding of the systems under investigation. There are a number of definitions in the literature from different perspective: discipline oriented, social life orientated, research oriented and educational oriented definitions and these are now discussed

Barry Richmond (http://www.hps-inc.com/st/st.html) defines systems-thinking as the, *'art and science of linking structure to performance and, performance to structure- often for purposes of changing structure (relationships) so as to improve performance'*. He proposed seven thinking tracks: dynamic thinking, closed-loop-thinking, generic thinking, structural thinking, operational thinking, continuum thinking and scientific thinking (Ossimitz, 2000). He also comments *'doing good systems-thinking means operating on at least seven thinking tracks simultaneously'* (Richmond, 1993, p. 121). Ossimitiz (2000) argued that these seven skills are good for doing systems dynamics modelling but most of them do not have much relevance outside system dynamic arena. However, Richmond himself recognized the problem of people becoming overloaded with the need to develop several skills. He commented, *'when these tracks are explicitly organised, and separate attention is paid to develop each skill, the resulting bite sized pieces make the fare much more digestible'* (p. 132)

System dynamics is often used interchangeably with systems-thinking but Richmond (1994) makes a distinction between these two terms (Ossimitz, 2000). Forrester and Richmond have argued about the relationship between systems dynamics and systems-thinking. To Forrester (in Segne et al., 2000), systems-thinking is a small territory on the system dynamics globe; however, Richmond argued the other way round by drawing a system dynamics globe with an atmosphere around systems-thinking. He explains *'systems-thinking is systems dynamic with an aura'* (Richmond, 1994, p. 4). However, his definition is still very much systems dynamics oriented. System dynamics is a powerful tool for understanding the interrelated system. Model building has been advocated for the expansion of systems-thinking to understand a system and is often practiced by the natural and social scientists (Hogan & Weathers, 2003).

Mandinach adds that systems-thinking is a scientific analysis technique and suggests that, *'systems-thinking approach consists of three individual but interdependent components: systems dynamics, STELLA and the Macintosh'* (Mandinach in Ossimitz, 2000). This definition is also restricted to computer modelling and is software oriented. These two definitions make it a prerequisite to have computer skills for systems-thinking. Ossimitz (2000) advocated the need for a definition of systems-thinking, which is independent of the system dynamics/ modelling approach.

Ossimitiz (2000) brings four dimensions into his definition of systems-thinking: firstly, *thinking in a model* which is the ability to understand the model that represents a particular system and also the ability to build models; secondly, *closed loop thinking*, nonlinear thinking - the ability to see interrelatedness and feedback loops between structural components; thirdly, to *view the retrospective events* (past events) and foresee the possible future of a system and, finally, *steering a system*, this is the ability to take action for system. These dimensions seem to be applicable outside the computer modelling. These four aspects refer to mental states and procedures to study a system rather than computer oriented skills.

According to Hogan and Weathers (2003) *'systems-thinking comprises skills that allow a person to analyze open systems (i.e., those that exchange matter and energy with a surrounding environment) by recognising how multiple factors interact, and by seeing and predicting patterns of change overtime'* (p. 234). Therefore, to them systems thinkers are the *'individuals who habitually look at things within the context of the environments that affect them, consider multiple cause-and- effect relationships, anticipate the long term consequences and possible side effects of the present actions, and understand the nature of change'* (p. 233). This definition seems to be applicable to all sorts of systems: biological and social systems. It has been regarded as a feature or a mind set to look for the long term effects. It is the ability or an effort to look back, look forward and look around the system for comprehensive understanding and making sound decisions. Hence it highlights three elements of systems-thinking: ability to analyse, ability to recognise and ability to predict or foresee.

According to Dorner (in Ossimitz, 2000), '*...it is a bundle of activities, and essentially it is the ability to use our normal, sound reasoning according to the circumstances of the individual situation.*' Ossimitz comments on this definition by saying that Dorner reduced systems-thinking to the following formula:

Systems-thinking = complex situation + situation adequate thinking

According to O'Connor and McDermott (1997) '*systems-thinking looks at the whole, and the parts, and the connections between the parts...*' (p. 2). Their perception of systems-thinking embraces three levels of understanding:

> The *first level* represents the stage in which knowledge about the structure and processes within the system is acquired.
> The *second level* involves understanding connections among parts of the systems with causal relationship among processes and their input and out put products.
> The *third level* involves understanding that output products of process may serve as the input product for another (Kali et al., 2003).

These three levels of understanding show the increasing complexity of developing understanding. Kruschwitz, Lyneis, and Stuntz, (2000) also talks about these components of systems-thinking. This analysis indicates a procedure and perhaps suggests that a system can be understood at any of these three levels: whole, individual parts and integration between parts, but seeing the whole is the highest level of understanding.

Smith (2003) described systems-thinking as '*an integral way of studying and interpreting the world in which complex systems are the context that frames the* *exploration'* (p, 329). This is a very general definition suggesting a mind set for thinking and perceiving the world around as linked and connected.

In a biology educational context, Verhoeff (2003) introduced systems-thinking as a competence which is a combined action of attitude, knowledge and skills that enable a task to be performed adequately. He argues that,

> *'Systems-thinking competence is the ability and willingness to link different levels of biological organisation from the perspective that natural wholes, such as organisms, are complex and composite, consisting of many interacting parts, which may be themselves lesser wholes, such as cells in organism'*
>
> (2003, p. 4).

This description makes systems-thinking a personal activity as well by involving willingness to be engaged in understanding complex systems by linking and connecting their components. Goldstone (2006) commented: '... *science is not self-integrating, and there are fewer and fewer people taking responsibility for net making'* (p. 35). Hence, to be a systems thinker one needs will and a sense of responsibility.

In the domain of biology, Capra (1997, p. 29) has stated that,

> *'The essential properties of an organism or living system are the properties of the whole, which none of the parts have. They arise from the interaction and relationships between the parts. These properties are destroyed when the system is dissected either physically or theoretically, into isolated elements. Although we can discern individual parts in any system, these parts are not isolated, and the nature of the whole is always different from the mere sum of its parts"*

This description provides a theoretical framework for systems-thinking in the study of living organisms and social systems.

Scheetz (in Senge et al., 2000) argues that systems-thinking is a continuum of concepts and practices. Its practical aspect makes the invisible process of thinking very visible by using different tools and techniques. Systems dynamics models are very powerful tools but are not the only tools. Senge (1990, 2006) expresses a similar view describing systems-thinking as a discipline for seeing the whole; a framework for seeing the interrelationships and patterns of change; a set of general principals; a set of specific tools and techniques; and a sensibility for subtle interconnections. He has proposed a number of qualitative tools for practicing systems-thinking and to communicating in a systems way of thinking and making the procedure of thinking observable. Richmond (1991) also described systems-thinking as a continuum ranging from conceptual to practical activities.

Looking at the views discussed above, they suggest the need for a habitual mind-set keeping in view the complexity of analysing a situation and proposing solutions. They provide information about this from different angles. This is now summarised:

Systems-thinking as:

- A product (systems dynamics)
- A scientific analysis technique
- A thinking process (mental state)
- Long term thinking (retrospection and prediction)
- Sound reasoning in complex situation
- A set of rules to study a system
- The highest level of understanding of a system
- An attitude and willingness to look for links and connections
- A way of interpreting the world
- A set of skills, abilities and activities.

Similarly, the purposes for developing systems-thinking as suggested by the discussions above can be listed:

Purpose of systems-thinking

- To improve performance of a system
- To make effective decision
- To take action for system
- To predict change overtime
- To handle complex situation
- To gain highest level of understanding
- To link different levels and their components
- To understand a system at a higher level

This leads on to looking at the nature of systems-thinking.

4.4 The Nature of Systems-thinking

Systems-thinking has been reported as a bundle or set of abilities and activities (Kali et al., 2003; Dorner, in Ossimitiz, 2000). Hogan and Weathers (2003), discussing systems-thinking in research team, present two major components of systems-thinking from the ecological research perspective: *cognitive* and *contextual components* categorising a series of elements necessary to practice systems-thinking in a research team. They talk about the expansion of systems-thinking where a number of personal and group oriented skills and practices are involved. They also argue that, in research fields, scientists expand their capacity for systems-thinking by adopting new approaches to interdisciplinary collaboration, new method of analysis and modelling and perhaps new attitudes and world views. Hogan and Weathers (2003) have suggested a list of the components of systems-thinking needed in research team work:

1 **Cognitive components**

(a) In depth knowledge
(b) Intuition
(c) Cognitive skills
  - Ability to identify or delineate boundary
  - Use of imagery and analogy
  - Construction of conceptual, empirical, mathematical models
  - Passion to understand complexity
  - Willingness to push boundary of current mode of thinking
  - Collaboration skills

2 **Contextual components**

(a) Social interaction
(b) Cross disciplinary interaction
(c) Temperament and personality
(d) Personal connections
(e) Shared passions

Carl Bereiter (in Hogan & Weathers, 2003) has proposed, from a psychologist's perspective, similar skills: knowledge, reasoning skills, motivation (intrinsic and extrinsic) willingness and emotional involvement to understand complexity etc. He views systems-thinking as a *suite of competencies* anchored in a particular context. It needs the activation of the whole suit of personal attributes that function as cohesive units in a context. He calls this a *'contextual module'*. Thus the whole suit of systems-thinking is evoked in a particular context. Regarding its multi-faceted nature, Hogan and Weathers (2003) argue that it is possible to address one or two components of systems-thinking empirically but it is difficult to examine the multiple components of cognition working together. Because of the multiplicity of the components and their interaction they called systems-thinking a dynamic system in itself. Ossimitiz (2000) shares the similar opinion concerning the difficulty associated with examining and measuring systems-thinking.

Kali et al. (2003) proposed that there are two elements of systems-thinking: scientific knowledge and cognitive ability. Knowledge can be in the form of facts, pattern, and complex structure. Newton called these forms of knowledge as relational components for developing coherent understanding (Newton, 2000). Cognitive ability is highly likely to influence systems-thinking. When the same amount of information is imparted, the same level of understanding does not develop among all the students. This reflects that some inherent ability influences the understanding (the product of linking and relating things together). Richmond (1991) regarded systems-thinking is a continuum of activities and he (1993) also further added that systems-thinking is one of the critical thinking skills.

Systems-thinking is considered as a higher order thinking skill needed in science, technology and also in everyday life (Kali et al., 2003; Assarf & Orion, 2005; Ossimitiz, 2005). Fisher argues that a high order thinking skill is not something beyond normal thinking skills rather it is a combination of ordinary skills. The high order skills are only the basic skills used in sophisticated combination (Fisher, 1992). Smith (2003) argues that complicated and complex situations engage and evoke the sophisticated way of thinking as well which suggests that systems-thinking is conditioned to complexity. Ullmer (in Assaraf & Orion, 2005) also comments that systems-thinking is an attitude of mind facing complexity. It has been reported that systems-thinking might be an innate ability (Gedovich in Kali et al., 2003).

To conclude, systems-thinking is not a single ability but a set of abilities; is a high order thinking skill; is conditioned to complex situation and is evoked in the face of complexity. The next question is *how to foster systems-thinking?*

4.5 Fostering Systems-thinking

Ossimitiz (2000, 2001) gives an overview of some of the possible ways suggested by many other researchers:

- Information campaigns for the sensitization for systems aspect;
- Computer simulation games ;
- Group-dynamics oriented approach in special seminars;
- Curricular concepts to develop systems-thinking skills via explicit teaching at school.

Out of these four possible ways, computer oriented ways have been found quite popular by many researchers. Forrester (2000) and Klieme & Maichle and Ossimitiz (2000) used computer modelling for teaching systems-thinking. Roberts (1978) used computer modelling with a younger sample to teach them concepts of dynamic feed back loops. Wilensky and Resnick (1999) have used software for making students think in levels. Richmond (1994) says that systems dynamics is an untapped potential for developing systems-thinking with its different tools. However, Scheetz (in Senge et al., 2000) argues that computer modelling is not the only way to teach systems-thinking. Senge (2000; Ossimitz, 2000) has introduced qualitative modelling for engaging into and also practising and developing systems-thinking. His tools include verbal description, behaviour over time diagrams and causal loop diagram etc. Richmond also favours the qualitative model building at school level before jumping to quantitative modelling.

Among these approaches to teach systems-thinking, Forrester (2000), Richmond (1993) and Ossimitz (2000) consider formal education important for developing systems-thinking. Hogan and Weathers (2003) propose that one of the educational goals should be to foster systems-thinking. However, little is known about systems-thinking in the context of science education and there is not much evidence from the published studies (Kali et al., 2003; Assaraf & Orion, 2005).

O'Connor & McDermott (1997) note the key problem: education does not keep up with the innovation because education systems are slow in responding to new ideas, as a result, the school syllabus lags behind societal developments. Forrester (2000) notes that schools are still operating in old traditional ways and, in spite of its enormous potential, formal education is not allowed to play its full role. Much of the problem rests with national curriculum planners who often are unaware of developments and are basing their plans largely on their own (and often distant past) school memories. Teachers are left to implement their plans and, because of the tight control of assessment, do not have the freedom to develop these in line with societal changes.

Smith (2003) reports that the literacies needed for future citizens are not being fostered by the American K-12 curriculum. The new literacies include the acquisition of new habits of mind, new set of diverse skills and alternate ways of perceiving and understanding. He also mentions that there are limited classroom activities to foster and support systems-thinking and a systems focused curricula is not apparent. He sees 'mental dexterity' as a need for future fully literate citizens. They need to analyse and also to develop systems-thinking as another tool of critical thought.

Richmond (1991) reveals another problem. Formal education has conditioned learners to analyse, to decompose and to attend to the detail of parts. This is largely controlled by the needs for fair assessment. This can measure recall and understanding of parts but has great difficulty in assessing that the learner can see things as a whole and can grasp the complex interrelationships between the parts. As this kind of skill is hard to measure, it is rarely assessed and receives little emphasis in the learning process. The importance of formal education in the teaching and developing of systems-thinking is clearly emphasised by Eastine:

> *'... Connections when brought to conscious practice through deliberate, repeated interjections into educational planning and instructional process, is a powerful, even transformational, force in the lives of both educators and students'*
>
> (Eastine, in Smith, 2003, p. 235)

Some studies have reported classroom oriented teaching and learning ways for teaching systems-thinking. Some examples are presented below. Hogan and Weathers (2003) and Smith (2003) advocate the *use of complex urban ecosystems* for teaching, developing and fostering systems-thinking. They argue that making sense of a complex systems in a context should activate the 'systems-thinking module' which is a combination of thinking abilities.

Assaraf & Orion (2005) advocate teaching of systems-thinking through instructional learning. Hence, Kali et al. (2003) and Assarf and Orion (2005) support the *inquiry based* learning both indoor and outdoor and also *knowledge integration activities*. Linn et al. (in Kali et al., 2003) also favour knowledge integration activities.

Smith (2003) has also proposed two ways of teaching systems-thinking: *asking questions* and *using activities* getting students involved with *discussing and doing*. He proposes that the teachers can help students by widening the context and adding more emphasis on relationship by asking relational questions (systems-based). Such questions are claimed to have transformational power. Asking such questions does not need new instructional material. What is needed is just an expansion of the anticipated outcomes of the pre-existing lessons. In this regard he (p. 340) comments:

> *'The quality of the questions posed, the searching for relationships, is the most important and the most powerful element of systems-thinking...for educationists. It is critical that the teacher consistently, repeatedly, and intentionally include the systems perspective in lessons'*

Martin, Mintez, and Clavijo's (2000) study does not directly involve the notion of systems-thinking. However, their study and results add to the debate. They have reported that engaging students in concept mapping is an effective tool for building up cross-linking between different components. They argue that the structural complexity of the map also gives a clue to students' understanding, and the process of developing it, and engages students in looking for relations among components.

Knipples (2002) developed a teaching learning strategy in genetics and described it '*yo-yo strategy*' to guide and facilitate the thinking in levels of biological organisation keeping in view the complexity of biological phenomena. Thinking forward and backward between levels and relating the key concept at each level was defined as an intended learning outcome. She also used a problem posing approach by asking questions and leading the students from higher level to the lower levels.

In another study in cell biology (Verheoff, 2003), systems-thinking was introduced as a meta-cognitive tool. Thinking between levels of organisation has been considered an important aspect of system thinking and also thinking backward and forward between the abstract systems model and concrete biological phenomena. He has also highlighted the horizontal coherence of knowledge at each level and vertical coherence at different levels of organisation as an important aspect of systems-thinking. He has used a model building activity and sequenced the text according to the levels to make students see the involvement of different levels and their components.

Smith (2003) has reported that the use of systems-thinking has been found very helpful in the teaching of urban ecosystems. In a study with environmental education, the experimental school which used the systems-thinking for teaching environmental education excelled in their performance on a standardised score. This success was attributed to the incorporation of system thinking in their teaching. Teachers felt that systems-thinking transformed their way of thinking, teaching and every day life as well.

Assaraf and Orion (2005) in the context of hydro-cycle system measured students' systems-thinking ability. Their study also dealt with the development of systems-thinking skills at the junior high school level in the context of hydro cycle. Similarly Kali et al. (2003) studied the development of systems-thinking in the context of rock cycle.

These studies suggest that systems-thinking can be developed by proper instruction and learning strategies. The environment in which the individual is embedded has a significant role to play in the development and enhancement of systems-thinking. It suggests that teaching activity shapes and guides the thinking pattern (Assaraf & Orion, 2005; Cramer, 1993).

Smith (2003) organised workshops to teach educators about the use of systems-thinking in environmental education and has argued that learning and using systems-thinking had a powerful impact on both the teachers and students in terms of their self esteem and empowerment; their ability to learn and internalise content and processes and acquire skills and their capacity to grasp complex issues and ideas. He states *'experience with students and their teachers suggest that using systems-thinking to study the environment has an extraordinary ability to make the chaotic and complex world we live in understandable. In learning and practicing this way of thinking and doing, students become hopeful, responsible, competent and empowered citizens'* (p. 329).

The studies discussed in this section have been carried out with different purposes: to measure systems-thinking, to teach systems-thinking, to develop coherent understanding by using the notion of systems-thinking in the teaching practice etc. However, Sweeny and Sterman (2001) argue that, although there is a call to develop systems-thinking to improve the ability to take effective actions, and that the fundamental questions are not being addressed: how do people learn to think systemically, what skills are required? There is little clear evidence about how this kind of thinking can be developed and a need for much more research and little attempt to link it to well established learning models. Indeed, there is more or less no evidence about when or where it can be developed: is it possible at school level or is it better left for post school courses?

Overall, this chapter has presented different views of systems-thinking, its nature, its need and its place in formal education. The next chapter will present the importance of genetics education and the problems associated with its teaching and learning.

CHAPTER FIVE

Difficulties Associated with Genetics Education

This chapter presents a brief description about the importance of genetics and genetics education, difficulties found in learning of genetics and the reasons behind these difficulties.

5.1 Importance of Genetics

Although the roots of biology can be traced back to antiquity, Mayer (1997) suggests that its origin as a modern science goes back to the middle of the nineteenth century to the period between 1828 and 1866. In recent years, biology has become a very exciting science. New discoveries are being made and much is happening in the research field to improve the quality of life (Tunnicliffe & Ueckert, 2007). Discoveries and advancements in the field have given birth to new sub disciplines in biology. Genetics is one of these disciplines; it appeared as a hot science after the discovery of DNA structure during the second half of the 20th century. Since then it has progressed rapidly. Genetics, particularly modern molecular genetics, is recognised as a fundamental aspect of modern biology (Martinez-Gracia, Quilez, & Osada, 2006). It is an important research field in biomedical sciences and it also has become central to biology education (Treagust & Tusi, 2007).

Discoveries, products and practices in genetics have a considerable impact on life. Genetics engineering and biotechnology have become involved in human life such as therapies, drugs and food products (Corn, Pittendrigh, & Orvis, 2004). Genetics engineering has revolutionised research in science, medicine, agriculture and law. All these advancements are seeking to make life and health better but they have given birth to new challenges and issues. The present modern society is now facing problems of decision making which were not known to the previous generations. Many of these issues arise from the products of this young modern science, genetics. For instance, farmers have to decide to grow or not genetically modified crops and individuals have to make a decision to use these products or not. There are similar ethical research issues related to human cloning, stem cell research, genetics discrimination and genetics privacy etc. (Venville & Donovan, 2007).

Thomson and Stewart (1985) argue that a good understanding of genetics is needed to survive in a society facing ethical, sociological and ecological issues. A sound knowledge is necessary to make informed sound decisions (Treagust & Tusi, 2007; Venville & Donovan, 2007) because knowledge provides basis for informed decision making (Dawson & Schibeci, 2003). The importance of genetics education grows and develops to meet this need and genetics literacy is important for the better understanding of genomics and the other related sciences as well (Knipples et al., 2005).

5.2 Genetics Education

Although genetics is a cornerstone of modern biology, it has been found to be a difficult area to teach and learn. More than two decades ago Johnstone and Mahmoud (1980) conducted a survey in Scotland of secondary school pupils and university students (undergraduates) and found them encountering difficulties in understanding genetics. Nearly twenty years later, Bahar, Johnsone and Hansell (1999) found the same perception of difficulty about the nature of genetics among Scottish undergraduates. Stewart (1982) and Finely, Stewart and Yarroch (1982) highlighted it as one of the most difficult areas not just for the students but also for the secondary school science teachers.

More recently a Dutch study (Knipples et al., 2005; Knipples, 2002) reported that secondary school pupils and their teachers are encountering problems with learning and teaching of genetics. This is confirmed in other parts of the world such as America, Kenya, Uganda, etc. (Thomson & Stewart, 1985). There is a widespread agreement that it remains a difficult subject to learn and teach at high school and also with undergraduates (Treagust & Tusi, 2007; Knipples et al., 2005; Rotbain ,Marbach-Ad & Stavy 2005; Bahar et al., 1999; Kindfield, 1991; Thomson & Stewart, 1985; Stewart, 1982; Finley, Stewart, & Yarroch, 1982; Johnstone & Mahmoud, 1980).

Research in science education has paid much attention to different aspects of learning and teaching of genetics. Knipples (2002) has reported that the focus of research has been shifted with the changing research interests. She identified three perspectives of research studies: *Piagetian perspective*, *cognitive perspective* and more *constructivist approaches*. These three perspectives have been recognised from their focus on varying aspects of genetics education. These will be discussed in the chapter six.

Studies originating from the Piagetian perspectives have reported that undergraduates and secondary school students find Mendelian genetics difficult because it needs formal reasoning skills to solve such problems and students lack such skills (Walker Hendrix & Mertens, 1980; Gipson, Abraham, & Renner, 1989). In this perspective such difficulties have been associated with the level of cognitive development. Walker et al., (1980) and Gipson et al. (1989) suggested that the curriculum should be designed according to the developmental stage of the students. However, studies from the cognitive perspective put emphasis on the concepts held by the learners and also how information is processed and this offers an important way forward (see next chapter a detailed discussion). From the perspective of constructivists, it is recognised that knowledge cannot be transmitted unaltered from the teacher to the learner but has to be constructed and built by the learners themselves. Thus, the previous knowledge of the learner has been considered as an important factor affecting the learning. Here the focus is on bridging the gap between the differences in the content and structure of personal and scientific knowledge (Knipples, 2002).

In spite of so much research conducted in this area from different perspectives, the difficulties still exist, no substantial solution has been found to deal with these problems and mostly piecemeal approaches have been put forward. However, some recent studies have started to tease out the issues which are at the heart of the problem and have suggested domain specific strategies for.dealing with the domain specific problems (Knipples, 2002; Knipples et al., 2005; Verheoff, 2003).

The following section offers a brief account of some of the difficult topics in genetics, reasons associated with these difficulties and some of the solutions reported in previous studies.

5.3 Difficult topics in Genetics Syllabi

Brown (1990) notes that, although there are other areas which are difficult to teach and learn in university and pre-university biology courses, genetics is reported to be at the top of the list. Most of the research has been conducted with the secondary school pupils. There are some topics from the genetics syllabi which have emerged as difficult ones repeatedly in the research studies (mostly conducted with the secondary school students).

Brown (1990) and Thomson and Stewart (1985) have identified problems related to Mendelian genetics for example problem solving involving mono and di-hybrid crosses. Rotbain et al., (2005) have reported that structure of DNA, RNA and the molecular processes such as replication, transcription and translation are the topics found to be hard to understand. Mitosis and meiosis have been found difficult (Lewis & Wood- Robinson, 2000) and this is confirmed recently by Chinnici, Yue & Torres. (2004) and Knipples (2002) reported them again to be challenging for many students, particularly those who are not science majors. This lack of understanding has been reported to be because of the confusion involved with the terms such as chromotid and chromosomes and also inability to understand replication, synapsis and disjunction (Chinnici et al., 2004). Similarly, genetic code, expression of inherited traits and genetic disorders have been found difficult to understand (Reiser & Duncan, 2007). Similarly, other related areas of genetics such as genomics, biotechnology, its processes and implications, have been reported difficult to understand for the school students (Corn et al., 2004; Dawson & Schibeci, 2003).

In addition to the students' learning difficulties in genetics, school teachers and university lecturers have their own problems regarding teaching. For instance the excitement and the advancements in the field have brought lots of worries for the biology teachers because there is so much biology around especially in the field of cell biology and molecular biology. In a recent conference arranged by the National Association of Biology Teachers in USA, it has been highlighted that the overcrowded syllabus and the pressure of exam results as one of the greatest dilemmas and challenges for biology teachers (Tunnicliffe & Ueckert, 2007).

Genetics education at university level has its own problems. For example, with the fast pace of incoming information, the field of bioinformatics is rapidly changing and new sub disciplines in biology such as proteomics, transcriptomics and metabolomics have emerged. This means that universities and commercial organisations such as research departments in the pharmaceutical industry in the government departments need suitably trained personnel with skills in the sub-discipline of bioinformatics (Delpech, 2006) and there seems to be a dearth of such experts in the field. Apart from this, university lecturers have been reported to be struggling having non-homogeneous classes (Tunnicliffe, 2006) and also with the students' attitudes towards learning biology because students may not be so passionate about the subject as their teachers (Tunnicliffe, 2006). Thus teachers have to work hard to present the subject in an interesting way which motivates the learners to be enthusiastic and which is challenging for every student in heterogeneous class.

Most of the educational research focuses on the problems of students' leaning, teachers' and lecturers' problems not being investigated much. The purpose of this chapter is, however, also to focus on the problems associated with students' understanding. Various reasons behind the learning difficulties in genetics have been reported in the educational research studies and these are now outlined.

5.4 Reasons behind these difficulties

Although it is widely accepted that the origin of difficulty may be different for different students (Modell, Michael, & Wenderoth, 2005) because individuals are different, however, there are some reasons which have been found to be general for almost all the learners. Different reasons have been attributed to the problems associated with difficulties in genetics education.

Johnstone (1991) reported that the learning problems are rooted in three areas in any science learning. He proposed that problem could lie in various places such as the *transmission system* (methods and facilities available); *receivers* (the learners) and nature of *message* (subject/ domain) itself. This suggestion is applicable to biology. Bahar et al. (1999) identified two reasons behind the difficulties of leaning genetics. These are the *intrinsic difficulties of the domain* and also *presentational problems* related to imparting the knowledge and information. Bahar et al. (1999) and Johnstone (1991) emphasised multilevel *thinking* as making genetics difficult to learn. Reiser and Duncan (2007) attributed students' difficulties in learning genetics to the *invisibility* and *complicated structure* of genetic phenomenon. Knipples (2002) highlighted *domain specific problems* such as the abstract nature of the subject matter and the complex nature of biological systems. A brief account of these reasons is presented below.

(1) Domain specific vocabulary and terminology

While the problem of terminology is not restricted to genetics only, the whole domain of biology is replete with an enormous technical vocabulary. The complex and extensive technical terms have been regarded as a source of confusion as they intimidate and overwhelm the learner (Pearson & Hughes, 1988a).

Twenty years ago, Pearson and Hughes (1988a) reported the problematic use of technical terms and classified the different types of difficulties associated with the use of some terms. These difficulties are the use of synonyms, the misuse of the terms and usage of obsolete or redundant terms. For example the terms 'alleles' and 'genes' are used interchangbly as a synonym which is incorrect. Similarly the terms 'test cross' and 'back cross' are used as synonyms. The use of synonyms creates confusion by overwhelming the learners.

Another problem lies when words are used in genetics in a specific way when the same words have different or wider meanings in ordinary usage. For instance the term ‘dominant’ is confusing for the students and they often associate its meaning with something which is frequent and common and thus they think that all the dominant alleles are good while all the recessive allele are bad (Pearson & Hughes 1988a). Albaladejo and Lucas (1988) reported that students often use the words out of context for example mutation is associated with the idea of change and some students consider the term, 'metamorphosis' synonym to 'mutation'. In addition, some obsolete terms in use also add to the problem causing confusion. Such terms no longer have real meaning because they have been superseded by other terms such as the term 'gene' which has replaced the term 'factor' which replaced the term 'element' used by Mendel (Pearson and Hughes ,1988a, 1988b).

This report about the problematic use of the technical terms by Pearson and Hughes (1988a, 1988b) is almost 20 years old. Much new terminology has emerged since. It has been stated *'technical vocabulary, like living language, is constantly changing and evolving with the new terms being added and overused terms losing much of their meaning'* (Pearson and Hughes, 1988b, p. 272). It seems that there is no way to escape from this terminological problem because one has to learn the language of the domain to understand and communicate. However, it has been reported that terminology causes learning difficulty only when the information sources for the students (teachers, text books) are victims of the problematic use of these technical terms (Knipples et al., 2005; Bahar et al., 1999; Verhoeff, 2003). Consistent and correct use of the terms and selectivity in their use has been recommended for the text book writers and also for the teachers in order to lessen the confusion caused by the use of large number of terms.

(2) Involvement of the knowledge from other disciplines:

Involvement of the knowledge from the other disciplines in understanding genetics concepts is another issue. Mathematics is a classic example because it involves a lot of calculation and symbolic representations of genetics concepts especially in Mendelian genetics (Bahar et al., 1999; Knipples, 2002; Thomson & Stewart, 1985).

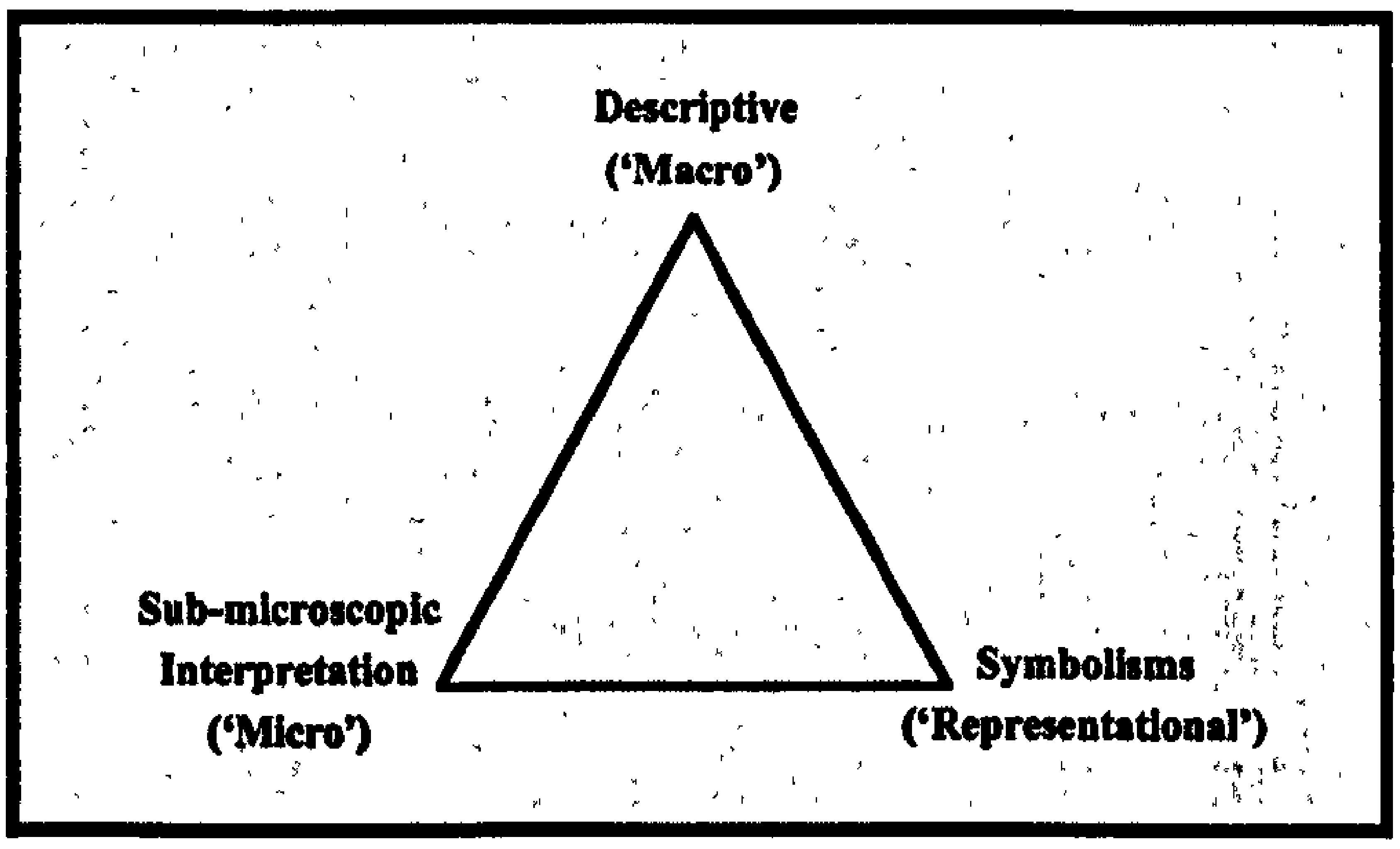
Apart from mathematics, chemistry and physics underpin understanding of some genetics concepts. Modell et al. (2005) have argued that challenges faced by the biology students appear to be more complex than those of physical sciences students.

They illustrated that in chemistry, students deal with concepts describing events at the microscopic (atomic, molecular) level and also at the macroscopic level. On the other hand, students in biological sciences must have a basic understanding of physics and chemistry and have to apply this understanding at different levels of biological sciences. The involvement of concepts from the other disciplines puts a cognitive demand on students. Thus conceptual difficulties related to physics and chemistry can lead to the conceptual difficulties in biology (Modell et al., 2005).

(3) Multi level thought problem:

Johnstone (1991) introduced a model in chemistry education distinguishing three levels of thought: the macro level, the micro/sub-micro level and the symbolic level (figure5.1). He described the *macro level* in terms of visible concepts and tangible objects; *micro/sub-micro level* as the invisible and intangible processes and entities and the *symbolic level* as symbols and equations involved in chemistry. He also stated that when these levels of thought are mixed and presented simultaneously, it causes learning problems for the new learners. He argued that the experts move on a triangle of thought level without any difficulty and can operate even within the triangle where all the three components of thoughts are involved. However, it is different with the beginners in the field who do not have this ability yet. They need time and experience to learn to think between the three corners of the triangle. Johnstone (1991) argued that presentations involving several thought levels simultaneously are not conducive to enhance learning because they put an additional cognitive demand on students. He also highlighted that teachers are mostly unaware of this demand being enforced on their students by shifting from one level of thought to the other and mingling them simultaneously. Many other researchers have reported that when concepts and processes belonging to different levels are presented simultaneously, students face a considerable difficulty in developing understanding (Marbach-Ad & Stavy, 2000). Johnstone saw all this in terms of information overload in the working memory.

Figure 5.1 Thought level model, adapted from Johnstone, 1991.



Bahar et al. (1999) also argued that the genetics difficulties are due to the involvement of different thought levels. They applied the same model to genetics as an attempt to find a remedy to deal with the complexity of genetics concepts which involve different levels of thought: macro level (plants and animals) micro level (cell) and biochemical level (DNA). They illustrated that in genetics many concepts are explained from the microscopic level (genes and chromosomes) which are normally represented as symbols. Through species described in words to population levels described in mathematical equations. Very often these concepts demand student to move across these three thought levels which they find difficult. Hence, it was recommended that teachers confine themselves to one thought level at a time during the teaching session and also to make gradual moves from one thought level to the other for the sake of new learners. In this way, the complexity can be controlled by operating initially on one side of the triangle at a time (Bahar et al., 1999).

Johnstone's model of thought levels has been found very useful for enhancing effective teaching and learning in science. It has been appreciated and has been applied in chemistry education by many researchers (eg. Yan Tsui & Treagust, 2004; Meijer, Bulte & Pilot, 2005). This model has also been used in biology education. Kapteijn (1990, in Marbach-Ad & Stavy, 2000) used micro/macro concept as a tool in teaching plant metabolism. However, Knipples (2002) has argued that Johnstone's model is not sufficient for biology education (Knipples, 2002) because of the nature of biology which is somehow different from chemistry and physics. In chemistry these three levels of thought are sufficient because it deals with components, elements and atoms but biological systems are different from the systems chemistry deals with.

Knipples (2002) and Verhoeff (2003) extended the idea of multilevel thinking in biology keeping in view the nature of the living system, the very object of biology education. Their models are not fundamentally different from Johnstone as the same thought levels are needed and are operated but what is unique about them is their taking into account the nature of the message. Johnstone said *'not enough thought has been given to the message'* (1999, p. 76). His idea has been a catalyst for biology educationists to think about their message and take in account the demands of its nature.

(4) Complex nature of biological systems

Previously Bahar et al. (1999) while talking about genetics teaching and learning mentioned the complexity of thought levels interacting with each other and making genetics difficult to understand. However, recently some research studies, particularly those of Knipples (2002) and Verhoeff (2003) have been designed involving the levels of biological organisation (the structural organisation of the biological system). This is a different kind of complexity inherent in the living system itself (Modell et al., 2005; Hogan, 2000). It has been stated that complexity of living systems lies in the heterogeneity of the components and the multiple levels of organisation involved which are hierarchically arranged (Hmelo-Silver & Azevedo, 2006; Wilensky & Resnick, 1999).

Reiser and Duncan (2007) applied an analytical framework to explore students' difficulties in understanding molecular genetics and identified the ontologically distinct levels involved in genetics phenomena: information level, containing genetics information, and physical level containing hierarchically arranged biophysical entities such as proteins, cells, tissues etc. Reiser and Duncan (2007) called genetic phenomena 'hybrid hierarchical' because they are hybrid of distinct levels which are ontologically different and are hierarchically arranged. To them, understanding involves bridging the information and physical levels to learn molecular genetics. Knipples (2002) and Verhoeff (2003) also share the same view on understanding the genetics concepts.

There are several levels involved in biology: molecular, cellular, tissue, organ, organism, population, community, ecosystems and biosphere (Reiser & Duncan, 2007; Verhoeff, 2003). Some of these levels are tangible and observable, others are beyond the realm of human unaided sight, some either too small (molecular level) or too big (eco systems, biosphere). The complexity of life science involving different levels of biological organisation and their heterogeneous components contribute to learning difficulties and the development of misconceptions (Modell et al., 2005). This brings complexity into the biological system and genetics is a complex area of biology.

Many researchers have reported that students have difficulty reasoning across different levels in genetics and in other contexts as well such as ecology, evolution, the respiratory systems and chemistry (Reiser & Duncan, 2007). It has been argued that when these levels, with their components and processes, are not interrelated during teaching it causes learning difficulties (Knipples et al., 2005). It has also been reported that teachers present information simultaneously from all levels, jumping from one to the other level, skipping one and landing on the next level in their explanations. They do not link the levels and their components explicitly and thus fragmented information is imparted (Veroheff, 2003). Students have been reported to take in information in an isolated form and store it as fragmented islands of knowledge (Kali et al., 2003) and thus their knowledge tends to be compartmentalised (Hogan & Weathers, 2003). Some recent studies in cell biology and genetics have shown that students find it difficult to link different pieces of information (Knipples, 2002; Verhoeff, 2003; Knipples et al., 2005). They also find it difficult to connect different concepts in genetics because these concepts and processes belong to different levels of organisation (Marbach-Ad & Stavy, 2000; Knipples, 2002; Verhoeff, 2003) or according to Riser and Duncan (2007) belong to distinct ontological levels. Hmelo-Silver and Azevedo (2006) have argued that understanding and reasoning about complex systems inflicts an enormous cognitive burden on working memory resources.

Reiser and Duncan's (2007) investigation revealed that students mapped the information inappropriately at multiple levels of organisation and described their explanations as *'truncated explanations'* where they linked the action of genes directly to the observable outcome without providing the mediating information. Similarly their explanations of genetic phenomena have been found lacking an explanation of the mechanism and thus were called *'tautological explanations'* (Reiser & Duncan, 2007). They observed truncated and tautological explanation among the 10th graders when they were asked to explain the genetic phenomenon. Similar problems of truncated and telelological explanations have been reported in ecology regarding trophic levels (Hogan & Weathers, 2003).

Issues of complexity are not only restricted to genetics. Other areas of biology are also facing the same problems. Students have been reported to be struggling to grasp the complexity of food web and of the energy flow, analysis of the structure and dynamics of ecosystems. It has also been reported that students do not see ecosystem as interrelated whole (Magntorn & Hellden, 2007). Similarly, problems related with multiple levels and several components in physiology have been reported by Modell et al. (2005). According to them:

> *'In physiology...students must deal with ion movement, molecular mechanism, and mechanisms at the cellular level, at the tissue level, at the organ level, at the system level, and the level of whole organism. In addition, students must be able to shift their focus among these levels of complexity depending on the phenomenon being considered or the problem being solved'*
>
> (Modell et al., 2005, p. 25)

This shows that multiple levels and their components contribute to making genetics and other areas of biology more difficult by overwhelming the students (Hmelo, Holton, & Kolodner, 2000). It has also been reported that there is a certain level of knowledge which students can take in and when demanded to move beyond they have difficulties. Tunnicliffe (2006) stated:

> *'Biology educators also need to recognise that there is a level of knowledge about a topic beyond which most learners do not proceed...understanding of the internal organs, and systems of the human body composed of constituent organs, rarely develops beyond an understanding of the main organs and their position in the body: the interrelationships of organs that form systems is seldom grasped.'*
>
> (Tunnicliffe, 2006, p. 99)

This suggests there are two levels of understanding of biological systems: anatomical or structural understanding of the systems; dynamic and functional understanding of the systems. It needs to be decided that what aspects of understanding of these systems are expected from the learners at each stage of their learning and then the teaching approach can be used appropriately.

(5) Problems of Visualisation

Martinez-Gracia et al. (2006) argue that molecular biology is regarded as difficult because it deals with abstract concepts which many students find difficult to visualise. Reiser and Duncan (2007) also reported that the invisibility and inaccessibility of the genetic phenomenon to the senses add to the difficulties in genetics learning because it involves small and often hidden entities and processes which cannot be experienced directly. For example, molecules are at the heart of biology, and yet they are possibly one of the most intimidating and alien concepts because of their invisibility, inaccessibility and abstract nature (Rotbain et al., 2005).

(6) Fragmented Nature of the Information Imparted

The difficulties in learning genetics are also associated with the way genetic knowledge is imparted. The two important and widely used sources of information are the text books and the teacher. Several studies conducted in different parts of the world have reported that textbooks have been found causing some problems in high school and university (Martinez-Gracia et al., 2006). Most of the studies conducted analysed secondary school text books (Knipples, 2002; Verhoeff, 2003; Martinez-Gracia et al., 2006). Text books have been blamed for presenting fragmented information, the lack of explicit relationships between concepts, inadequate presentation of levels of biological organisation, while drawings and activities have also been criticised.

A Dutch study (Knipples, 2002) reported that, in secondary school text books, the proper sequencing of the genetics content was missing; topics that are naturally linked such as reproduction, meiosis, and inheritance were separated in time and space. Similarly, Marbach-Ad and Stavy (2000) reported text books dealing with the concepts belonging to different levels in different chapters. It was suggested that fragmentation contributes to the abstract nature of genetics and makes it difficult to learn. It has also been reported that school books and teachers also do not make the links explicit between different genetic concepts for the students (Knipples, 2002; Verhoeff, 2003).

Another Dutch study by Van de Put (2001, in Knipples, 2002) analysed how the textbooks deal with the levels of biological organisation and reported an inaccurate use of levels of biological organisation. Implicit changes of levels of biological organisations were found, use of simultaneous presentation of multilevel was observed; the concepts of a phenomenon were not found to be starting with the concrete macro level and finally relationships between different genetic concepts were not made explicit. It was also reported that authors of textbooks did not seem to be aware of the learning difficulties associated with the levels of biological organisation (Knipples, et al., 2005).

It might appear that this argument runs counter to the suggestion proposed by Bahar et al. (1999) to confine the teaching to one level. However, this need not necessarily be true because he also advocates moving to the other levels gradually. The key is that early learning in any new area must start with the components perhaps not very well integrated. However, it is vital that, at later stages, these parts are brought together to give a more coherent whole. Thus, students may need to start at a specific level and then, later, bring together their understandings from several levels.

Martinez-Gracia et al. (2006) conducted a survey of genetics text books in Spain for high school and found that many molecular genetics concepts such as DNA transcription, regulation of gene expression and translation were presented as a large amount of information which did not facilitate the process of learning. In addition, the meaning of some genetic terms was poorly presented. Moreover, the fragmented way molecular genetics is being presented was highlighted. Hence, it was suggested that molecular biology should be set in a broader context of cell and whole organism biology.

It seems that, in spite of the emphasis from cognitive research on the connection of ideas, many text books for high school and general college text books offer biology in a piecemeal way where one chapter deals with one topic with very little integration among topics being found (Seethaler, 2005).

Apart from the written material, books also use drawings and chemical formulae. Rotbain et al. (2005) have reported that drawings presented alongside the running text remain isolated from the text and are not referred to. Apart from the isolated nature of the diagrams in the midst of written text, sometimes abstract and complex figures are presented which do not add to the understanding of the students. Similarly, text books and teachers use chemical formulae to represent the structure of the molecules. Such types of representation have been found difficult to understand by the high school biology students especially if they are not taking a chemistry course.

The use of worksheets has also been criticised when students have just to fill in few words because such activity requires very little thought (Tunnicliffe & Ueckert, 2007). Marbach-Ad and Stavy (2000) have stressed the importance of emphasising integration activities in teaching and learning to bring together the different levels. Similarly it has been reported that students need to be able to make cross-domain connection to respond to the current scientific issues. However, it has been realised that science curricula neglect this activity (Seethaler, 2005). If students are to link the ideas and develop deeper understanding, then it is essential that the emphasis is put on making connections within and across subject areas (Tunnicliffe & Ueckert, 2007). In addition to this, the assessment practice has been found to be causing a lack of coherent understanding. It has been reported that teachers feel unable to teach biology in a holistic way because their time is occupied with teaching the information that students need to pass the exam and little time is available for sense making and connecting the information (Tunnicliffe & Ueckert, 2007).

Another aspect of biology teaching which has come under criticism in higher education is the extensive use of power point presentations (Tunnicliffe & Ueckert, 2007; Kinchin, 2006). It has been reported that slide presentation has a negative impact on teaching: it encourages passivity in class room (Tuft, 2003 in Kinchin, 2006). Lecturers present the important points in the form of bullet points and students tend to note the bulleted phrases. Such teaching has been reported as resulting in the learning of 'biology bytes' and not in developing an understanding of biology concepts (Tunnicliffe & Ueckert, 2007), however, this is difficult to demonstrate. Similarly, information load on slide presentation has also been criticised. It has been suggested that, if the load is reduced, learning will improve considerably (see Johnstone, 1997; Yuan et al., 2006; Cook, 2006). Kirschner et al. (2006) make the same point from a cognitive load perspective that any educational strategy which ignores the limiting nature of working memory capacity is highly unlikely to enrich the learning process.

It has also been reported that computer presentations tend to be very linearly structured, perhaps resulting in rote learning. In this regard, perhaps the use of a concept mapping format for presentations might help. It could lead to teaching as knowledge construction rather than knowledge transmission (Kinchin, 2006). It seems unfair to criticise presentations only, making them responsible for students' lack of understanding and learning. Students' interests, motivation and their previous knowledge are also what decide how learning happens. However, the need for coherence and connectivity in presenting information in this visual way is required and emphasised.

5.5 Students' Understanding

Due to all the problems associated with teaching and learning genetics, students' understanding of the phenomenon differs in a class. The mental representations about one concept may vary in a classroom and these representations can be distributed over a spectrum ranging from an ill-defined or ill-formed mental model to well-defined and well-informed ones (Modell et al., 2005).

It has been reported (Modell et al., 2005) that students' mental models are often flawed: they may not conform to the accepted models; links between different elements of the students' model may not be appropriate; they may be lacking an appropriate level of complexity, the individual elements may not have a well integrated place in the model; misunderstanding may originate from the differences in the use of language. Similarly, the difficulty may originate from a faulty mental model of fundamental physical and chemical phenomenon, inappropriate integration of appropriate mental model of physical and chemical phenomenon, informal learning and previous knowledge of what was learnt in school. All these factors interact with the students' developing an understanding of the discipline (Modell et al., 2005).

In addition to knowing about the facts, concepts and principles of a subject, new knowledge must be organised in some sort of mental representation to make links with the already existing knowledge and for the one which will be acquired in the future (Modell et al., 2005). Similarly, students have difficult in developing a coherent cognitive model of the domain and they find it hard to link the characters and the molecular mechanisms involved (Gelbart & Yarden, 2006).

However, *'the teacher cannot correct the students' mental model. Only the student can modify his/her mental model'* (Modell et al., 2005, p. 23). The only thing teachers can do is to present the information in a way that takes into consideration the complexity of the subject and also the attributes of the learners. In this way slowly and gradually students would start developing a coherent understanding because *'the ideas cluster as only a few isolated island, and only very slowly begin to* *come together to form the reasonable networks that the teacher desires'* (Marbach-Ad & Stavy, 2000, p. 200).

Many research studies have reported different teaching approaches or strategies which have tried to facilitate the process of learning in genetics. The general approach has been that researchers explored the problems students were facing, tried to give reasons behind them and also developed solutions to foster students' learning in difficult areas by using different methods: traditional, non-traditional and computer assisted programmes and activities. Most of the published studies have been conducted with secondary school pupils. However, most of these studies did not look for fundamental underlying reasons for the difficulties and their solutions may not be generalisable. The work of Chu (2007) stands out in that she re-cast an entire syllabus so that working memory overload would be minimised and then compared the performance of a large sample with that of a sample taught in the traditional way. She was able to show a marked performance improvement for those using the revised approach. Before attempting this, she was able to demonstrate that working memory capacity was highly correlated ($r = 0.52$) with performance in a genetics examination.

Rotbain et al., (2005) used a ***drawing based activity*** to make students learn better the structure of DNA. Corn et al., (2004) used ***analogies*** involving daily life; such as town (cell as a small town), library (nucleus), books (genes), encyclopaedia (DNA), tabloid pages in encyclopaedia (Junk DNA) and factories (ribosome) etc. The purpose was to develop a sound foundation of elementary knowledge and fostering students' comprehension about the topics such as genetics and genomics. Similarly, Chinnici, Yue and Torres (2004) developed a simple way for students to ***role-play*** mitosis and meiosis. They reported that such group activities helped in decreasing the amount of stress and negative attitude towards a topic. It also provided an exposure to as many of the senses as possible because it involved multiple methods of learning such as seeing, reading, hearing and physical participation. Such combination enhanced students' learning about meiosis and mitosis. Colucci-Gray (2006) also used role-play as a tool to deal with the complex socio-environmental issues and conflicts.

Hohenshell, Hand and Staker (2004) used a ***writing activity*** to promote conceptual understanding of biotechnology. They made 10th graders to write and explain for 7th grader. The younger audience was used to make the older students avoid regurgitating the terminology they had learned in their class. The purpose was to compel students to write in a simpler language and to construct their own understanding. This was found helpful in developing deep understanding by probing down and going beyond just using the technical terms. It helped students to construct their own understanding of the topic by getting involved in deeper thinking about the concept (Hohenshell et al., 2004). Similarly many other researchers have worked with many other strategies to facilitate the process of learning.

It has also been reported that the capacity to enhance the quality of learning experience is greatly influenced by the instructional media. Currently computer assisted learning is becoming popular and educational programmes are being developed to foster learning and understanding. Corn et al. (2004) argue that computer-assisted instruction has been found as useful as the traditional methods.

A number of studies have been reported using computer assisted teaching aids. For example, ***Bioinformatics*** is a new approach in which biology, information technology and computer sciences are merged. It has been used with the high school and college students and also with the high school biology teachers to understand junk DNA by visualising it through bioinformatics tools (Elwess, Latourelle, & Cauthorn, 2005). Similalry, Gelbart and Yarden (2006) developed a ***web based learning environment*** in bioinformatics and reported that it had been found to influence students' acquisition of a deeper and multidimensional understanding of the genetics domain.

There is also a realisation that a single instructional approach is not sufficient to meet the needs of diverse student population (Tunnicliffe & Ueckert, 2007). Yan Tsui and

Treagust (2004) have suggested using a multimedia approach for multiple representations of the phenomenon such as verbal, textual, mathematical, visual and real life observations. In this regard, Cook (2006) has argued that the multiple presentations can enhance the working memory capacity by reducing the overload of information through addressing different channels of perception. Yan Tsui & Treagust (2004) argued that computer based multiple representations hold promise in providing opportunities for sophisticated understanding of genetics. However, it has been argued that expensive equipment is not essential for good biology education. Students need explicit guidance for understanding the complex concepts (Tunnicliffe & Ueckert, 2007). If, in the use of technology, the pedagogical principles are forgotten, instead of facilitating learning it can impede learning and cause frustration.

Knipples et al. (2005) observe that analysis of the problems in teaching and learning genetics is common while seeking to find a strategy to address these problems has been less frequent. They focused on understanding the problem to find out a potential sustainable solution. Knipples et al. (2005) and Verhoeff (2003) used the notion of systems-thinking to address the issues of complexity and abstract nature of the subject. They explicitly took into account the nature of the message (biological systems) for finding a domain specific solution. Knipples (2002) introduced the levels of biological organisation in genetics and proposed a yo-yo strategy to explore the relationship between the levels of biological organisation. Later on Verhoeff (2003) applied that strategy to the cell biology.

Knipples (2002) and Verhoeff (2003) used the problem posing approach in genetics and cell biology respectively using systems-thinking. They used questions to take students' understanding at the concrete level and then gradually descended down the levels of biological organisation. Verhoeff (2003) involved the students in model building of the system. He also facilitated the learning process by reducing the complexity as he divided and sequenced the content according to the levels of biological organisation. He proposed that sequencing the reading content according to the levels of biological organisation would reduce fragmentation and bring coherence. He also suggested teachers using yo-yo approach (taking students up and down on the levels of biological organisation) explicitly and also making links between different concepts and different pieces of information. Knipples and Verhoeff also suggested having a top down teaching approach by starting on the phenomenal level of the organism that students are familiar with and then descending gradually.

It is being realised that biology deals with complex systems and thinking about complex systems is becoming an increasingly important skill. Therefore one of the educational goals should be to foster systems thinkers:

> *'...systems thinkers, i.e. people who habitually analyse phenomena and problems as situated in wider context; consider multiple cause and effect relationship; anticipate the long term consequences and possible side effects of present actions; and understand the nature of change over time'*
>
> (Hogan & Weathers in Hogan, 2000, p. 22)

There is general agreement that genetics is difficult. While many features of the nature of genetics and the way it is often taught may be contributing to the problems, the fundamental reason why it is difficult may simply lie in the information overload (or cognitive overload, using the language of Kirschner, et al., 2006) which is so often a feature of genetics learning. The problems related to the nature of message (subject matter) and the transmission system (presentation of knowledge) have been teased out in this chapter. The work of Chu (2007) was based on the fundamental problem of information overload and the improvement in performance was found to be quite marked when this was taken into account. Genetics, by its very nature, lends itself to systems-thinking. Drawing together the findings from information processing and the nature of genetics seen as a complex system may offer useful way forward.

Before this is pursued, the next chapter explains different findings of the educational psychologists about the nature of learners (receiver) and how learning takes place.

CHAPTER SIX

Learning Models

After exploring the learning difficulties in the previous chapter, this chapter summarises the findings of several key educational psychologists. This seeks to offer a brief overview of what learning is; how it takes place; and also instructional or pedagogical insights which can assist effective and efficient learning.

6.1 What is learning?

A variety of answers can be offered to this question. A general accepted view of learning is that it is a systematic modification of behaviour; it is related to knowledge construction based upon prior experience and is seen in terms of a change in performance (Weick, 1991). However, learning is not only just the observable outcomes. It also occurs when attitudes, feelings and intellectual processes are modified or changed (Hamachek, 1995). It has been described as an increase of content, gaining skills and facts, and organising information in long term memory (Hassan, 2003) and as a change in long-term memory (Kirschner et al. 2006). These views about learning reflect a single notion described in a variety of terms: modification, construction, change, transition, increase, gain and organising. Learning may happen consciously and unconsciously, under good or bad conditions.

6.2 Models of Learning

For well over a century, researchers have probed into how learning takes place and also presented models of learning. These models fall into two broad categories:

(a) Behaviouristic models;
(b) Cognitive models.

Both categories of models agree that learning is a modification or change in behaviour based on experience; however, there are differences as well. Firstly, for behaviourists, the learner is considered as a passive recipient (Watson, 1913). For cognitivists, the learner is an active processor of information (Johnstone, 1997a &

1997b). Secondly, to behaviourists, learning is an observable change in behaviour while, for cognitivists, learning is a process of gaining or changing insight, outlooks, expectations and thought patterns. They associate learning with developing understanding. Thirdly, behaviourists do not discuss what happens internally when learning occurs but cognitivists look for the internal mechanisms and mental processes which bring about learning (Yang, 2000). Finally, the behaviourists believe that practice and reinforcement shape learning while cognitivists are concerned about the ways to help students become more effective processors of information (Mayer, 1992).

The cognitive view of learning was a significant shift from behaviorist view of learning (Bruner, 1966). Understanding of learning and learning processes shifted gradually over the years. Human learning was first seen as a *'response acquisition'*, influenced by rewards and punishment; later on, in 1950 and 1960, as *'knowledge acquisition'*. In 1970s and 1980s, cognitive models of learning matured with a new view of *'knowledge construction'* (Hamachek, 1995). The development of information processing models from the 1980s [such as early work by Atkinson and Schriffin (1968) and the seminal work of Baddeley (1986)] laid the foundations for more fully-fledged information processing models (eg Johnstone & Kellett, 1980; Johnstone & El-Banna, 1986, 1989; and Bruning et al., 1995).

Before information processing came of age, there were many major contributions mainly from educational psychology. Some of them are presented below.

6.3 Piaget's Theory of Cognitive Development

Piaget (1896-1980) never practiced as an educator and did not intend to contribute specially to education and teaching but his work has had considerable significance for education and teaching (McNally, 1974).

Prior to Piaget, the child was thought to be rather like a miniature adult and learning was often conceived as the transfer of information. However, Piaget regarded the child as an active participant in the process of intellectual development. He described the growth and development of intellectual structures *schemata,* which keep on modifying themselves through life and through processes called *assimilation* and *accommodation.* When children gain knowledge, they construct schemata. Assimilation is fitting the new information into the existing schema while accommodation is the alteration of existing schema. Thus, cognitive development is a constant adjustment of the balance between assimilation and accommodation (Flavel, 1963).

He observed that the child's cognitive structure develops and grows up through a series of distinct stages (Piaget, 1968):

Figure 6.1 Piaget's Four Stages

Stages of Intellectual Development	Description
Sensorimotor *(birth to 2 years)*	Differentiates self from objects Recognises self as agent of action and begins to act intentionally Achieves object permanence, realising that things exist even when no longer present to the senses.
Pre-operational *(2 to 7 years)*	Learns to represent objects by images and words Language facility and grammar expand enormously Classifies objects by a single feature eg colour or height
Concrete operational *(8-11 years)*	Can think logically about objects and events Achieves conservation of number (age 6), mass (age 7) and weight (age 8) Can classify objects according to several features and can order them in series along a single dimension
Formal Operational *(11 years onwards)*	Can think logically about abstract propositions Can test hypotheses systematically Becomes concerned with the hypothetical, the future, and ideological

There is a general consensus that all children in their mental development pass through these stages in the same order. However, the rate of development differs from child to child. Age boundaries are a rough estimate but the child can operate at one level in one context while moving to the next level in another. The stage age differs from person to person with different cultural backgrounds and socio-economic factors (Hyde, 1970; Campbell, 1976; Atkinson & Shriffin, 1968)

Piaget has been criticised for claiming rigid age boundaries, using poor sampling and down playing experience and environment as influential in the cognitive development (e.g. Ausbel, 1963, 1968; Lovell, 1974; Novak, 1978; Jenkins, 1978; Dawnson 1978). Indeed, stages are not clear cut and individuals do not move sharply or in neat ways from one stage to the next, perhaps operating at two different stages in two different contexts. However, Piaget's descriptions are remarkably well-founded (Herron, 1975).

His great importance also lies in his historical contribution. This offered a new insight and led to an enormous amount of work in the field of cognitive psychology and learning theory.

6.4 Vygotsky

Vygotsky, unlike Piaget, included social and cultural interaction as key elements in the process of learning. He (1962) presented a social cognitive theory stressing three underlying themes: the importance of culture; the role of language; the idea of a zone of proximal development.

Both Piaget and Vygotsky see the child as an active participant in development and acknowledge the role of environment but they differ in emphasis. Vygotsky states that the child is embedded in his environment and his development cannot be understood by detaching him from the social environment. On the other hand, Piaget downplays the role of social interaction by merely stating that environment can accelerate or retard the age at which the child is passing through the stages of development (Tudge & Rogoff, 1989).

Piaget emphasises the role of peer-interaction (although in his later writing he also acknowledges the role of the adult). However, Vygotsky advocates interaction with a more skilled partner who knows more than the child. To him, ideal partners are not equal; their inequality lies in their understanding. He emphasises that interaction with only peers could lead to delay in development; lead to abnormal development and can cause regression according to standards (Tudge & Rogoff, 1989).

Vygotsky also introduces the idea of *'the zone of proximal development* (ZPD)'. It is the difference between the actual mental age of the child and the level s/he gains in solving problem by some kind of assistance which he calls *scaffolding*. The zone of proximal development differs from person to person. With assistance or scaffolding some children can go to higher levels of achievement while others may not go far from their actual level. The children with larger ZPD do much better in school than the others with small ZPD (Bigge & Shermis, 1999).

Vygotsky's major contribution was in recognising the importance of the more skilled person taking forward the learner and enabling him/her to function at a slightly higher cognitive level. This led, more recently, to the idea of cognitive acceleration by which, through group work with challenging situations, some school pupils are enabled to progress to higher cognitive levels, thus increasing performance in examinations (Shayer & Adey, 2002).

6.5 Bruner's Model of Discovery Learning

Bruner's research and thought (Bruner, 1968) was greatly influenced by Piaget but he does not accept his idea of innate stages and development (Bigge & Shermis, 1982). Although he also talks about the 'steps' of human development and learning, he does not directly link them to age. He stresses that some environments can slow the sequence of development down or bring it to halt while others move it along faster (Bigge & Shermis, 1999). Piaget emphasised the biological growth of cognition while Bruner considered learning as a function of experience by saying that culture (environment) around the person unlocks and empowers the processes to learn (Bigge & Shermis, 1982, 1999).

There are two central themes in Bruner's learning model: firstly, acquisition of knowledge as an active process; secondly, construction of knowledge by relating incoming information to a previously acquired frame of reference. Existing cognitive structures provide meaning and organisation to experience and allow the individual to go beyond the information provided. When the cognitive structure interacts with the new incoming information, it changes or adapts itself in the light of the new information (Sirhan, 2000).

Bruner views learning processes as a combination of three simultaneous processes: acquisition of new knowledge, transformation of knowledge and checks on the pertinence and adequacy of knowledge which may be a refinement of the previous knowledge or may be in contradiction to a person's previous information. In transformation of knowledge, knowledge is manipulated to fit into new tasks. Transformation is achieved through extrapolation (to go beyond the information given) or interpolation (to change the existing knowledge through new incoming knowledge) while the pertinence and adequacy of knowledge is checked by evaluating the plausibility of the knowledge to the task at hand (Bigge & Shermis, 1982, 1999).

He asserts that any model of instruction must be concerned with the nature of the: (a) knowledge to be learnt (b) learning process and (c) individual learner. While talking about the nature of knowledge, he identifies three things which must be kept in view: firstly, its mode of representation (enactive, iconic or symbolic); secondly, its economy (the amount of information needed to develop understanding; thirdly, its power (its capacity to enable new connections to be developed).

He emphasises that the form and structure of the knowledge must be matched with the ability of the learners. He also talks about the motivation and willingness of the learner. To him it is important that the learners build their own coherent conceptual structure by active involvement. He argues that learning is not static but a dynamic social activity. He advocates for discovery and suggests that the information should not be presented in its final and organised form. Rather, students should be taught in such a way that learners discover relationships among facts, concepts and generalisations and organise them in their own long term memory. He also suggests a spiral design for curricula so students build upon what he or she has already learnt (Borich & Tombari, 1997; Bigge & Shermis, 1982, 1999).

Bruner's main contribution was his emphasis on discovery learning, emphasising the way the learner construct their own understandings (Sirhan, 2000).

6.6 Ausubel's Assimilation Model of Learning

While Bruner focused on a discovery learning model, Ausubel emphasised reception learning (Ausubel et al., 1978). In *reception learning,* students are not involved in any independent discovery. The content to be learned is presented to them in its final form by the teacher or in written finalised form (Novak & Gowin, 1984; Sirhan, 2000, Ausubel et al., 1978). The learner has to make an effort to internalise or incorporate this content into his or her cognitive structure (Ausubel & Robinson, 1969) while, in discovery learning students have to undertake some kind of mental activity such as arrangement, recognition or transformation to discover and then incorporate it into cognitive structure. He claims that it is laborious to rediscover which is already discovered (Novak & Gowin, 1984; Sirhan, 2000, Ausubel et al., 1978). Education should be an economical way to present discovered material.

He was concerned with how students learn and retain immense amounts of information as organised bodies of knowledge (Hassan, 2003). His model emphasises the influence of prior knowledge on new learning. He sees previous knowledge acting as a framework for incoming information because it enables information to be selected and incorporated into the learner's cognitive structure (Hassan, 2003; Sirhan, 2000). Ausubel et al. (1978) makes a very powerful statement:

> *"If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly".*
>
> (Ausubel, 1978)

In his theory of learning, Ausubel introduces seven key concepts related with learning. These are meaningful learning, rote learning, subsumption, progressive differentiation, superordinate learning, integrative reconciliation and advanced organisers (Novak, 1984). Among these seven concepts, the first two are related to the very nature of learning, the next four represent the ways learning occurs and the last one represents the methodology to facilitate learning. These concepts are briefly presented.

His central idea is that meaningful learning is '*non-arbitrary, substantive and non-verbatim incorporation of new knowledge into cognitive structure*' (Novak, 1984, p. 608). In non-arbitrary incorporation of knowledge, the learner has to make conscious and deliberate efforts to relate new information to the existing framework of knowledge. In substantive learning the key concepts are identified from the incoming information and are related to the already existing concepts. Rote learning is arbitrary, non substantive and verbatim at its best where words can be recalled and reproduced but understanding may be lacking (Novak, 1984; Novak & Gowin., 1984).

Ausubel introduced the term '*subsumer*' for the existing mental structure acting as an anchor for the new information. The process of linking the new information with the pre-existing cognitive structure, he calls '*subsumption*' (Novak, 1984) which alters the form of both the subsumer and the new information. He identified two different kinds of subsumption: derivative and correlate. In *derivative subsumption*, the main established idea (superordinate) is not changed. New material is an example of the previous established idea and is a kind of support or illustration of the existing one. In *correlate-subsumption*, the incoming information brings about extension, elaboration and modification of the existing subsumer. Hence, two kinds of knowledge can be identified: *subsumed knowledge*: accepted and linked information with the existing one and *unsubsumed knowledge*: the information which is learned independently and remains isolated without any connection with the subsumer (Ausubel et al., 1978; Novak, 1984).

Progressive differentiation means that concepts are modified, elaborated, made more precise, inclusive and exclusive. It is a life long process and never comes to completion (Novak, 1984; Ausubel et al., 1978). *Superordinate learning* occurs where new concepts are learned which provide meaningful relationships between two or more existing concepts or bridge the gap between two concepts. In addition, *integrative reconciliation* occurs when concepts, whose meaning at first appear unrelated or contradictory, are later integrated and related in a new way and result in a more powerful cognitive structure; it is a recombination of already existing cognitive structures (Novak, 1984; Ausubel et al., 1978). To facilitate the process of subsumption, Ausubel introduced the idea of a *'advanced organisers'* (Novak, 1984; Ausubel et al., 1978) which is *"a small learning episode that is more general and more inclusive than the material to be followed"* (Novak, 1984, p. 608). It could be just any verbal statement presented to the learner before the presentation of new knowledge. Advance organisers prepare the existing cognitive structure for recognising and subsuming the new information (Ausubel et al., 1978; Novak, 1984).

The main conclusions of his model are: meaningful learning takes place, firstly, if the content presented is logical and relatable to the existing content; secondly, if the learner possesses relevant ideas in cognitive structure which relate to the content presented; and thirdly, if the learner possesses the intent to relate these ideas to the existing cognitive structure.

6.7 Gagne's Conditions of Learning Model

Gagne's views were influenced by Ausubel's meaningful ideas and Bruner's work about mental processes but he was considering skills training rather than school learning. Gagne presented his model on the conditions of learning and then developed a model of instruction on its basis (Gagne, 1970). Gagne clearly called his model an instructional theory as it was never intended to be a learning theory because he did not state what the procedures of learning are or how they work (Gagne, 1985).

For Gagne (1985) learning is a process of change in human capability for various performances that persists over a time and is not dependent on the process of growth. Although learning is an unseen internal process, it can be inferred from learning outcomes. He states five categories of learning outcomes: intellectual skills; cognitive strategies; verbal information; attitudes; motor skills. He assigns four elements to the learning process: The learner; the stimulus situation; the organised content recovered from memory; response.

In his theory of instruction, he argues that learning is the learner's own business and s/he has to struggle to let it happen. The only help which can be provided to the learner is to change the external environment positively and constructively which in turn will effect the internal environment to let learning happen. That is why he puts emphasis on the set of events around the learner and argues for improving external conditions to facilitate and support the internal processes. This external support he calls 'events of instruction' which form the external environment or stimulus situations for the learners.

His stimulus situation in a class room is composed of nine phases: gaining attention, informing learners of the objectives, stimulating recall of prior learning, presenting stimulus, providing learning guidance, eliciting performance, providing feedback, assessing performance and enhancing retention and transfer (Gagne, 1985). These conditions of learning stimulus situation are appreciated in determining the sequence of instruction (Sirhan, 2000).

Gagne does not put emphasis on internal conditions explicitly but, in 1970, he argued for the importance of prior knowledge for determining the further learning. His approach advocates the logical sequence of steps: sequentially structured content. He argues that only those who have necessary pre-requisite for the absorption of new information can learn meaningfully (Gagne, 1970 and 1985).

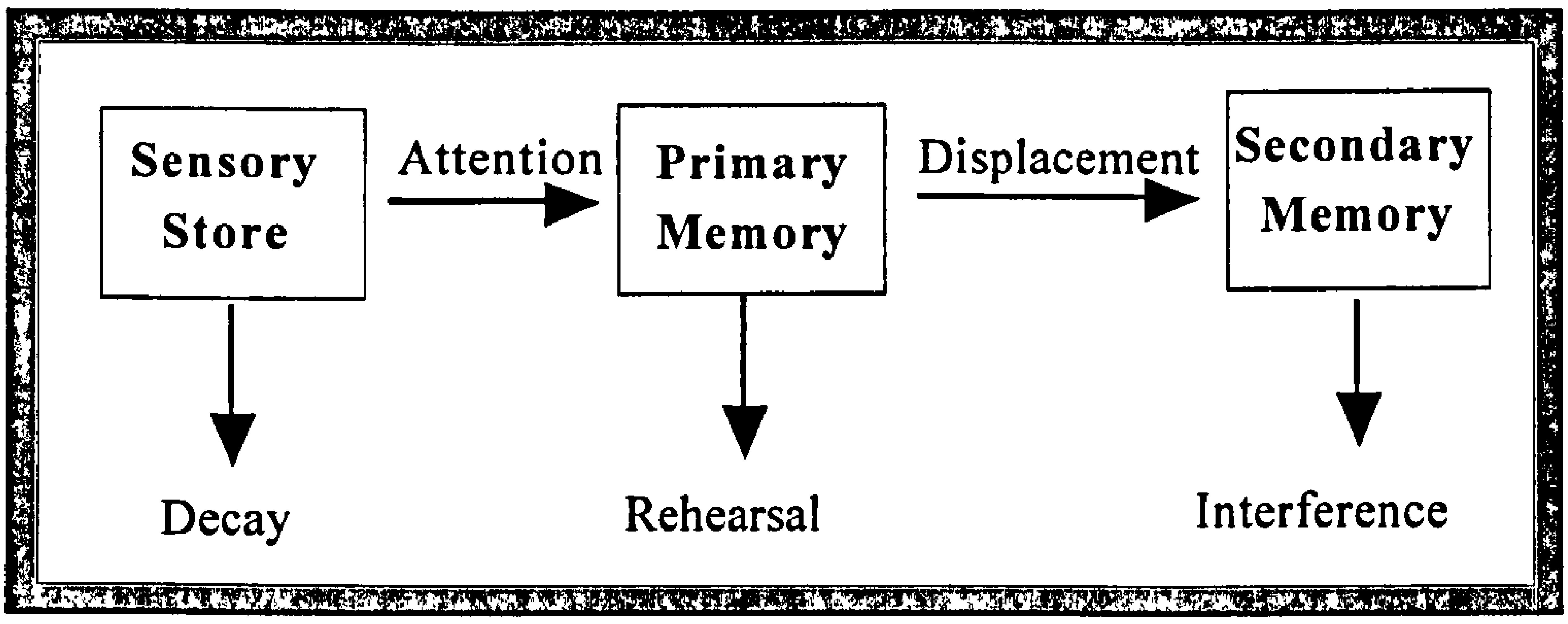
Overall, he looked at the logic of subject teaching and emphasises that material must be analysed so that it can be presented in logical order with each new idea building on previous ideas. It is difficult to argue with the logic of Gagne's position, however, it has to be kept in mind that learning ideas in such neat logical ways is not always observed. Howe (1975) found evidence that school pupils developed all kinds of idiosyncratic ways of learning which did not correspond to the apparent logical structure of subject matter.

6.8 Information Processing Models

The above models of learning offered very useful insights. However, Johnstone (1993) argued that, in all these models, the mechanism of learning was missing. Such a mechanism might offer insights into learning difficulties and ways by which learning might be limited or enhanced (Johnstone, 1993). Such a mechanism is found in the information processing models which have grown up alongside the development of computer (Johnstone, 1993). There are two aspects to information processing models: the *structure* of the information processing system and the *processes* which take place in the system (Eysenck, 1968)

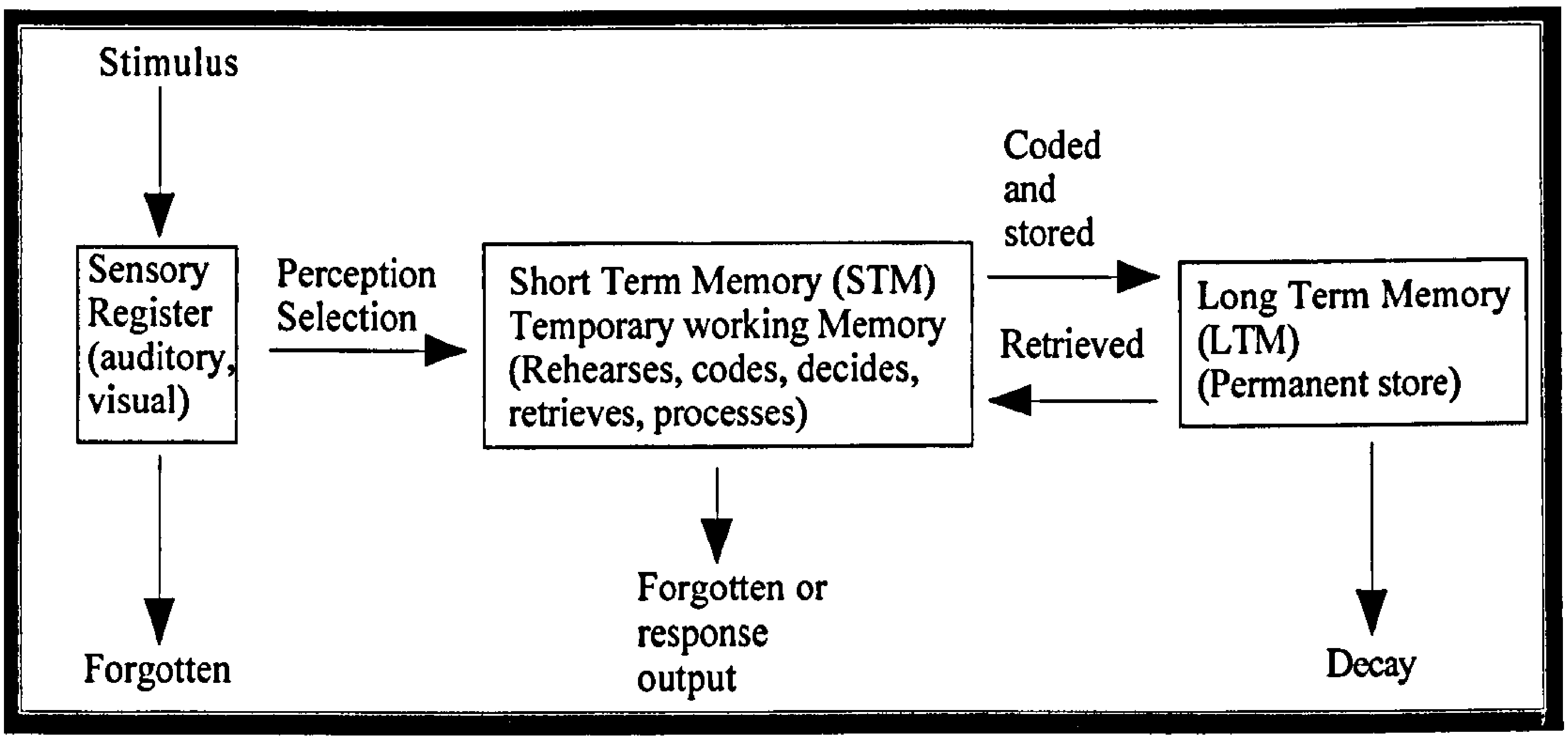
The first information processing models of human memory were of the structural variety and were put forward in 1950s and 1960s. These models assume that incoming information is held in *sensory store* for a very short span of time. This information is either attended or left unattended; unattended information decays, attended information goes into another store, called *short–term store*. Finally, information may be sent to a *long-term store* which seems permanent in nature. Waugh and Norman (1965) applied the term 'primary memory' to short–term store and 'secondary memory' to long–term store (Norman & Wickelgren, 1965; Atkinson & Schriffin, 1968).

Figure 6.2 **Sensory Stores**



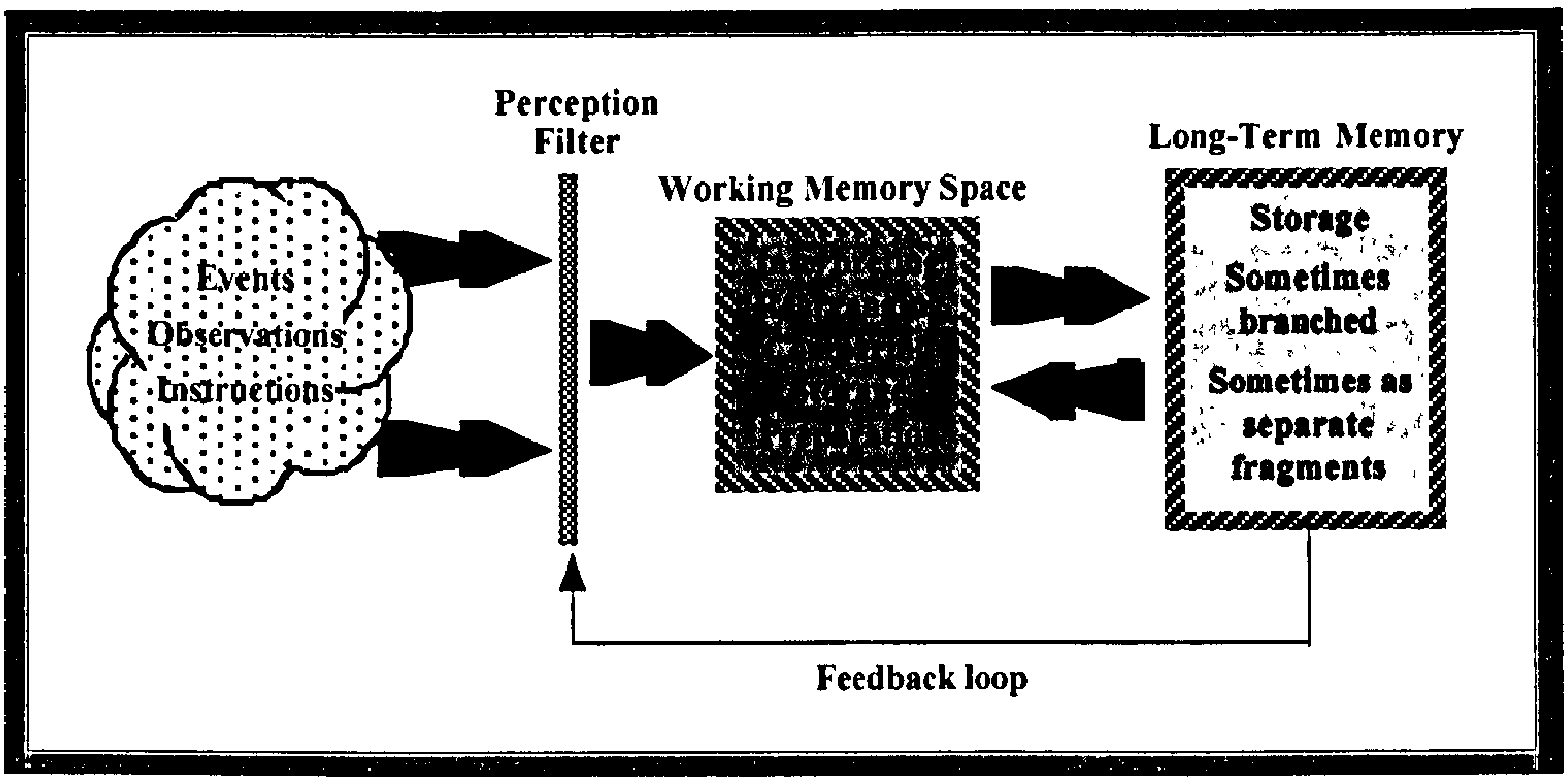
Another multi-staged structural model based on the models provided by Atkinson and Schiffrin (1968) and Baddeley (1994) identifies the stages commonly included in information processing models. This model depicts the flow of information between the three interrelated memory stores. This model also shows a control process that operates on the short term and long term stores.

Figure 6.3 Multi-stage models



Johnstone, after a sustained research programme, developed an information possessing model (Johnstone & El-Banna, 1986; Johnstone 1984, 1991, 1997, 1999, 2000). This model is shown in figure 6.4.

Figure 6.4 Information Processing



This model is comprehensive. It shows the flow of information through the memory system and also represents the act of processing of information necessary for constructing meaning. It is also predictive about how the information is handled by the system. The following is a description of each part of the model.

6.8.1 The Perception Filter

Johnstone (1993) named the sensory memory a *'perception filter'* and this is where the learner selects information that is important to him/her. It stores information for a very brief period. Ashcraft (1992) describes two types of sensory memory: *visual sensory memory* receiving visual stimuli and holding it for about one second and *auditory sensory memory* which receiving auditory stimuli holding it for about four seconds. The perception filter does not work independently and it is influenced by the long term memory. This is one of the key features which had been observed previously by Ausubel (1968). From the vast range of incoming information, the person selects what is meaningful, relevant or important on the basis of what is already held in long term memory.

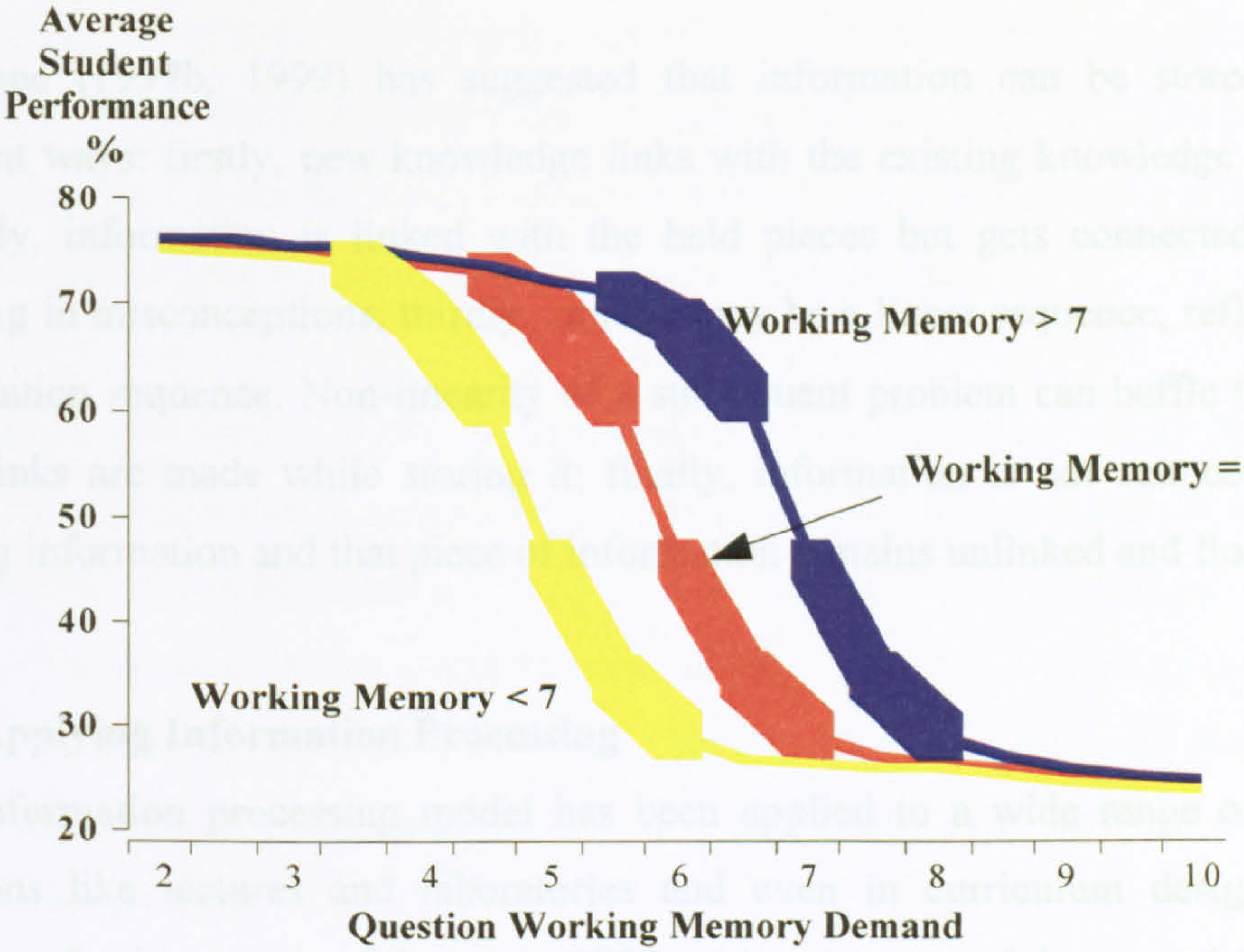
6.8.2 Working Memory

This is the conscious part of the mind (formerly called short term memory: Baddeley, 1976; Logie, 1995). Johnstone made a distinction between short term memory and *working memory space* in terms of the way that part of memory is used. Working memory is that part of the brain where we hold information, ideas and facts, work upon them, organise them and shape them before storing them in long term memory. Hence, it is a *shared holding and thinking space* where information interacts with itself and also with the information drawn from long term memory (Johnstone, 1984).

The working memory space has been found to be limited. If there is too much information to hold, then there is no space left for processing and if there is too much to be processesed then little can be stored. Miller (1956) developed ways of measuring working memory capacity and then demonstrated its limited capacity. In an average adult individual, its capacity is found to be 7 but the most adults fall between 5 and 9 spaces (7 ± 2). A space can hold one unit of information and the unit is what the individual *sees* as one unit. The size of the unit can increase; the size of working memory space cannot be expanded. However, this space can be used efficiently in various ways. The term 'chunk' was used first by Miller himself (1956). A 'chunk' means what the observer perceives or recognises as a unit: it can be a letter, a digit, a sentence, a group of numbers or a formula (Johnstone, 1997a 1997b). The more a 'chunk' holds, the more the working memory can hold.

Johnstone (1997a & 1997b) shows how the model is predictive. If a task has a demand on working memory which exceeds the space available, then the task becomes impossible. Johnstone (Johnstone & El-Banna, 1986) explored this in detail. In one major experiment, he looked at the students' success rate with a series of questions in an examination paper and related this success to the working memory demand of the questions. The working memory of each student was also measured and the students divided into three groups. The results are shown here in diagrammatic form:

Figure 6.5 Performance and working memory capacity
(After Johnstone and Elbanna, 1986)



The feature of their results which have been confirmed by other works (eg Christou, 2001; Tsaparlis, 1998) is that high performance *suddenly* drops to very low performance when the limits of working memory capacity are exceeded. This reveals the importance of working memory as a rate determining step in learning.

6.8.3 Long Term Memory

Johnstone (1999) describes three main functions of long term memory. Firstly, it activates and controls the perception filter. The feed-back loop from long term memory to perception filter is an indication that nothing is learnt objectively and, in fact, what is held already in long term memory 'decides' what is important. Secondly, it makes stored information, cognitive skills and chunking procedures available to the working memory space. Chunking procedures are those procedures which allow several pieces of information to be perceived as one piece, an aspect developed originally by Miller (1956). Thirdly, it acts as a vast reservoir or store house on a relatively permanent basis to hold knowledge. It is not just a factual store. It always contains opinions, bias, beliefs, likes and dislikes, experiences, thus making us different from each other. It has unlimited capacity but the retrieval system is not always efficient. Information is forgotten but this may simply be that it cannot be found in the 'filing system' but actually nothing is lost only mislaid.

Johnstone (1997b, 1999) has suggested that information can be stored in four different ways: firstly, new knowledge links with the existing knowledge correctly; secondly, information is linked with the held pieces but gets connected wrongly resulting in misconceptions; thirdly, storage may be a linear sequence, reflecting the presentation sequence. Non-linearity of a subsequent problem can baffle them if no cross links are made while storing it; finally, information is not connected to the existing information and that piece of information remains unlinked and floating.

6.9 Applying Information Processing

This information processing model has been applied to a wide range of learning situations like lectures and laboratories and even in curriculum design for the learning of sciences (see Johnstone, 1997a). At one stage, Johnstone developed a completely new first year university course in chemistry and, in drawing together all the strands of research he could find at that time, he suggested ten principles for teaching and learning. These are given overleaf:

(1) *What you learn is controlled by what you already know and understand.*
(2) *How you learn is controlled by how you have learned successfully in your past.*
(3) *If learning is to be meaningful it has to link into existing knowledge and skills, enriching and extending both.*
(4) *The amount of material to be processed in unit time is limited.*
(5) *Feedback and reassurance are necessary for comfortable learning, and assessment should be humane.*
(6) *Cognisance should be taken of learning style and motivation.*
(7) *Students should consolidate their learning by asking themselves about what is going on in their own heads.*
(8) *There should be room for problem solving in its fullest sense to exercise and strengthen linkages.*
(9) *There should be room to create, defend, try out, and hypothesise.*
(10) *There should be opportunity given to teach (you do not really understand until you teach).'*

Although this set of principles was devised to meet a very practical situation, each statement was based on empirical evidence. The first three describe the role of long term memory while the fourth principle takes account of the limited capacity of working memory. Principle five notes the importance of affective nature of learning while principle 6 extends this to individual differences. The final four principles are practical applications which encourage meaningful learning.

Information processing offers an explanation and description of all learning. In highly conceptual subjects many ideas, of necessity, have to be held at the same time. The possibility of information overload is, therefore, high and this explains why such topics often pose so many problems. In biology, genetics frequently poses such problems because a large number of ideas have to be held at the same time in order to gain some kind of understanding of what is happening. This has been discussed in the previous chapter.

It is evident from this brief account of learning models that learners construct their own understanding. To facilitate the process of learning, only the pedagogical approaches can be manipulated by presenting the information keeping in view the two things: the nature of the discipline and the general attributes of the learners in terms of how they are known to learn (Verhoeff, 2003; Knipples, 2002; Johnstone, 1999; Cook, 2006; Kirschner et al., 2006; Yuan et al., 2006).

The following chapters present the research design and the methodology adopted for each phase of the project, their findings and conclusions.

CHAPTER SEVEN

Research Design

In the previous chapters, the complexity of biology, systems biology, systems-thinking and its application in many areas of life has been explored. It can be argued that biology, as a discipline, needs systems-thinking because it deals with complex systems. Genetics has been reported specifically as one of the most difficult areas. It involves multiple levels and relationships within and between levels, resulting in the complexity. Learning models, especially information processing, have shown that some of the difficulties may be due to the way information is presented and the limitation of working memory capacity. The explorations suggested using systems-thinking in genetics education and to investigate if it assists the learning process.

This chapter highlights the purpose statement, research question and the objectives of the current research project; describes the nature and overall view of the research study including the evaluation of methodological issues and how the research project was planned and conducted.

7.1 The Purpose Statement and Research Question

The purpose of the present study was to explore the impact of using systems-thinking in biology education. In this regard, the key task was to develop and use teaching and learning material (in the context of biology) using the notion of systems-thinking. The overall research question was:

What are the possibilities and impact of using systems-thinking in biology education?

In order to answer the central research question, the project revolved around achieving the following objectives.

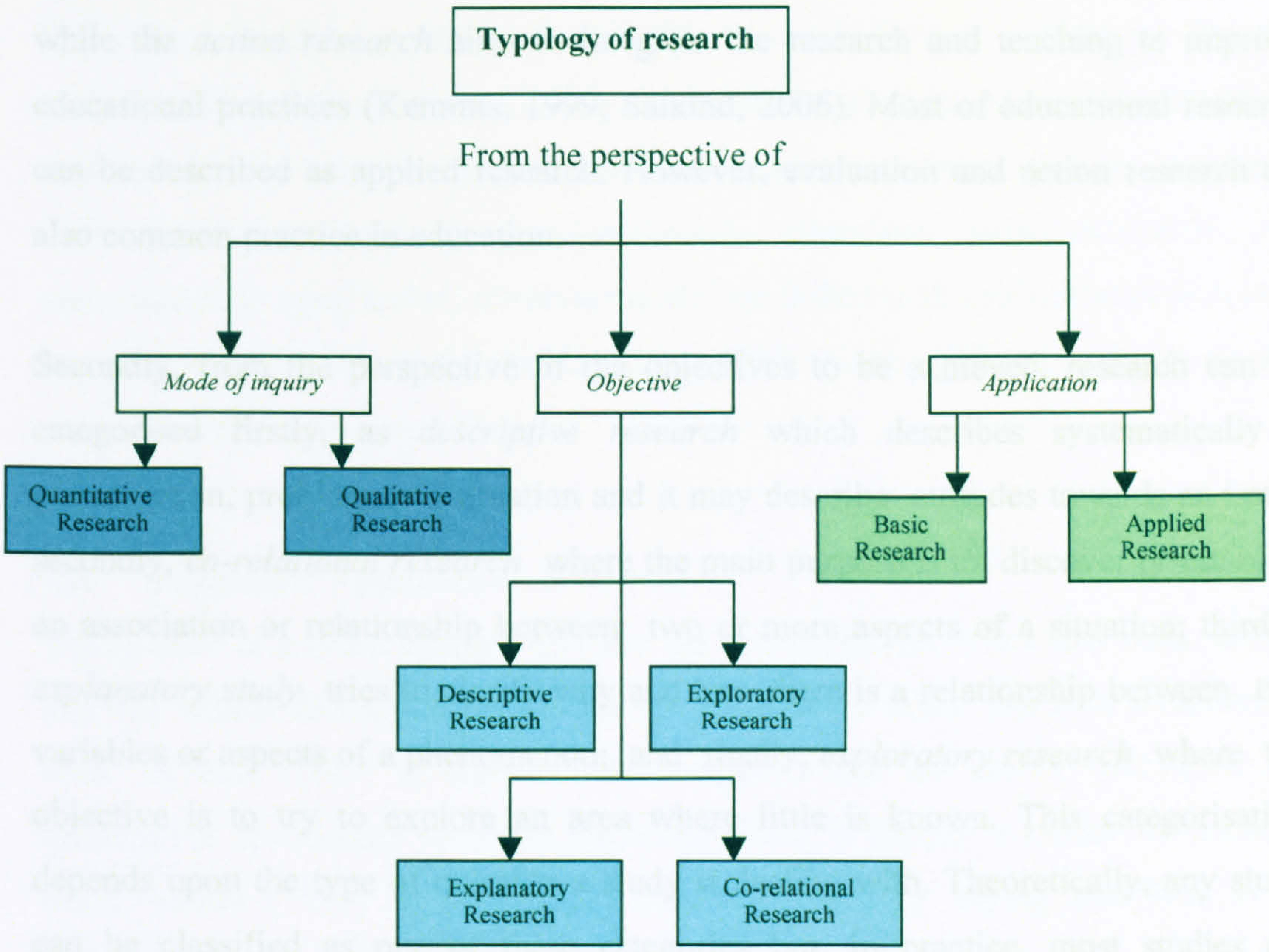
- *To explore the way to use systems-thinking in developing systems-based teaching and learning in biology education;*
- *To investigate how students deal with the systems-based teaching and learning experiences.*

The way this was carried out is now described.

7.2 Issues of Methodology and Research Design

Different approaches to conduct research are identified in the literature (Kumar, 2005; Keeves, 1999; Creswell, 1997; Robson, 2002). In the light of these approaches, any research study can be viewed from different angles. Kumar (2005) presented a broad research typology (see fig 7.1 for categorisation of research approach). He has not included all the other known categories of research. Nonetheless, it serves as a lens to see a research study from three different perspectives: from the perspective of application, of the objectives to be achieved and of the mode of inquiry.

Figure 7.1 Typology of research from three different perspectives (adapted from Kumar, 2005)



Firstly, from the perspective of application, a study in education can be categorised as basic or applied research depending upon the anticipated use of the research findings (application). If the findings of the research add to the existing body of knowledge and there is no immediate and direct application for the benefit of the society then the research is labelled as *basic research*. However, it always has the potential to be applicable for the benefit of the society in the future. Basic research is concerned with the development, examination, verification and refinement of research methods, procedures, techniques and tools that form the body of research methodology. In the research field, very little research is designed as basic (or pure) research which has no immediate application at the time of its completion (Kumar, 2005, Salkind, 2006). On the other hand, *applied research* has immediate practical application for the benefit of the society (Kumar, 2005; Keeves, 1999) focusing on a problem that needs to be solved or improving practice in a particular field (Mcmillan & Schumacher, 2006). Kumar has only mentioned applied and basic research in his typology but evaluation and action research also fall in this category. *Evaluation research,* as its name indicates, investigates and evaluates a programme for an organisation or for an institute to make decisions about that particular programme, while the *action research* aims to integrate the research and teaching to improve educational practices (Kemmis, 1999; Salkind, 2006). Most of educational research can be described as applied research. However, evaluation and action research are also common practice in education.

Secondly, from the perspective of the objectives to be achieved, research can be categorised firstly, as *descriptive research* which describes systematically a phenomenon, problem or a situation and it may describe attitudes towards an issue; secondly, *co-relational research* where the main purpose is to discover or establish an association or relationship between two or more aspects of a situation; thirdly, *explanatory study* tries to clarify why and how there is a relationship between two variables or aspects of a phenomenon; and finally, *exploratory research* where the objective is to try to explore an area where little is known. This categorisation depends upon the type of question a study is dealing with. Theoretically, any study can be classified as one of these categories but, in practice, most studies are combination of these categories (Kumar, 2005).

Thirdly, from the perspective of mode of inquiry (type of data collection method), Kumar has included two types of research in his broad typology: *quantitative and qualitative.* Mixed method research is not part of his typology although this is becoming a favourite mode of inquiry.

The qualitative and quantitative research paradigms have been well documented in the literature regarding educational research (Kumar, 2005; Robson, 1999, 2002; Keeves & Lakomski, 1999; Walker & Evers, 1999) while the twentieth century has seen a conflict between these paradigms (Husen, 1999). Various names are used: quantitative has been termed as traditional, positivist, experimental or empiricist; while the qualitative paradigm has been termed as constructivist approach, interpretive approach, post positivist or post modern (Creswell, 1994; Walker & Evers, 1999). A long and hot debate has been reported over the implications of these two paradigms because they stand in contrast on ontological, epistemological, axiological and rhetorical dimensions.

Moreover, the entire process of a study (its methodology) differs for the two traditions. The methods of data collection and analysis are specific to both traditions of research. For example, questionnaires and structured interviews are associated with quantitative research paradigm while interview (semi structured, and unstructured or open ended) observation etc. are linked with qualitative paradigm of research practice (Creswell, 1994, 2003, 1997). Such differences have divided researchers for quite a long time.

7.3 Pragmatic Approach to Research

Whilst there is a sharp contrast between the two traditions, it has also been realised that this radical dichotomy between the two traditions exists mostly at a theoretical level. Bryman (1989, in Geelen, 2003) suggests that the use of qualitative and quantitative approaches within a particular study is simply a matter of common sense. Husen (1999) is also of the similar opinion by saying that here is no unbridgeable gap between the two traditions in practice. He also suggests that they might not be as incompatible as it is argued by both sides. Creswell (1994) comments that the two paradigms are not regarded as exclusive but they complement each other. The complementary nature of the two approaches has been demonstrated by those who have used the mixed method approach and have actually shown that integration of these two traditions within the same study has the ability to augment the findings.

In recent research literature, studies are classified as mono-method (either qualitative or quantitative) or mixed method. The idea of combining the different approaches can be traced back to the second half of 20th century. A brief overview of the evolution of ideas for combing two approaches is presented here. Influential methodologists such as Campbell and Stanley have advocated the *multiple method approach* where one can integrate the data collection methods from one paradigm (Niglas, 2000). Creswell (1994) has previously called it '*within method approach*', which means one can combine different types of either quantitative or qualitative data collection instruments. For example, one can combine interviews with observation or video recording etc.

The idea of combining methods was taken further by suggesting that the combination of quantitative and qualitative research would overcome some of the problems that a pure design (qualitative or quantitative) of research could not overcome (Niglas, 2000). This approach to research has been called a "*mixed method approach*" or pluralistic approach (Cress well & Tashakari, 2007; Geelen, 2003). Creswell (1994) has termed it previously as "*between methods approach*" which means that the methods can be combined from quantitative and qualitative data collection strategies. For instance, one can combine survey questionnaire (quantitative) with the interviews (qualitative).

A variety of terminology in the literature can cause confusion especially to new researchers. Different labels are used for the same idea and, at the same time, authors use the same terms with different meanings as well (Niglas, 2000). Based on the classification of Abbas Tashakari and Charles Teddlie, Niglas (2000) has identified two different terms and ways in which mixed method approach is used: firstly, *multi-method design* in which both the quantitative and qualitative approaches are used but they remain relatively independent until the interpretation stage; Secondly, *mix designs* where elements of qualitative and quantitative approach are combined in various ways within different phases of the study. The description given by Niglas about the *mix design* is equivalent to Creswell definition of mixed method research. Creswell advocated the inclusion of both approaches at all stages of research, not only in data collection but also in analysis, interpretation and inference drawn from the results (Creswell & Tashakari, 2007). It can be said that *mix design* is more integrative approach than *multi method design. Multi method design* is like two parallel running rivers which are joined at the far end. However, mix design is also like two parallel rivers but they intermingle on their way at different intervals before they are merged into each other at the far end.

There are number of possible rationales behind using the mixed method approach. Bryman (1988 in Geelan, 2003; Bryman, 2004) has proposed different purposes of using mixed method approach to research such as triangulation, facilitation of quantitative research using qualitative research, and vice versa. He also states that quantitative research captures the structure while qualitative research captures the processes. Quantitative research also adds in making generalisations possible (Bryman in Geelan, 2003). Creswell (1994) argues that mixed methodology adds expansion to the scope and breadth of study by bringing richness and detail to study; it also results in the development of a research design where the results from the first method is used sequentially to shape the subsequent method or steps in the research processes and it stimulates new research question or challenges the results obtained through one method (Creswell, 1994). Moreover, complementarity has been suggested by Green et al (1989, in Niglas, 2000) as a way of using mix method approach. By complementarity, they mean clarifying, illustrating, interpreting the results from one method with the result from the other (Creswell, 1994; Niglas, 2000).

In the current research literature on mixed methodology the term *triangulation* tends to be overused and even abused (Niglas, 2000). Originally, Denzin (1978, in Creswell, 1994, 2003; Geelan, 2003 and Niglas, 2000) developed the concept of triangulation in research. Generally, triangulation means multiple measurement of the same phenomenon. In this regard, Bryman (1989, in Niglas, 2000) has identified different types of triangulation such as *data triangulation, investigator triangulation, theory triangulation* and *methodological triangulation.* The rationale behind triangulation is often described as attempts to neutralise the biases inherent in one data source, investigator or method (Niglas, 2000; Creswell, 1994). However, according to Denzin and Lincoln (1994 in Geelan, 2003), triangulation is not an attempt, tool or strategy of validation and accuracy. As it reflects a positivistic implication that some unchanging phenomenon exists and triangulation can be a logical check. This positivistic view of triangulation to look for accuracy and validation has been viewed as a naive view by Geelan (2003) although it has to be admitted that triangulation can offer encouraging support for test validity. He adds to the debate and thus has widened and extended the meaning of triangulation by commenting that the overall purpose of triangulation is to get stronger and richer understanding; and to create richer and thicker description of the complex phenomenon. The current study embraced this extended meaning of triangulation.

In the light of this discussion, two schools of thought have been identified: purists who believe in mono-method research (either qualitative or quantitative) and pragmatists who argue that there is a false dichotomy between the two research traditions. Pragmatists argue that the researchers should make the best use of both the tradition in developing, designing and conducting their study. This view is adopted in this study.

7.4 Rationale for the Research Approach

The description of this study needs to be seen against the background of the above discussion. This study cannot be seen as either qualitative or quantitative for it embraces both. It is a mix design study and multi-tasked research project. Different data collection methods were used to achieve different objectives. The specific details of the mixed approach will be unfolded in the following chapters.

This approach has been adopted for the following reasons. Firstly, there were some specific questions for which it was considered best to use a qualitative method. For instance, semi-structured interviews were used where the opinion of the respondents was being sought. In other areas, the best approach was considered to be quantitative. For example, survey questionnaire and other tests were employed. The selection of data collection method was based on the richness of the data which that method could yield. In other words, at this point the researcher embraced pragmatism to get the maximum potential advantage from both the research traditions.

Secondly, a mixed design was used to grasp the rich picture of the problem being investigated from different perspectives and also to devise the best solution for the problem. For example, different methods were used to investigate the situation in biology education, to explore the depth and breadth of the specific area involved and covered under the umbrella of this project. In addition to this, mixed methodology also served to shape the subsequent steps of the research project. For instance, one phase set the stage for the next task. All the specific details of methodology applied in this research project, regarding the data collection instruments, analysis and findings and sample etc. will be described in detail in the coming chapters.

Using the lens of research typology, the current study can be viewed from three different perspectives.

Purpose: it is a combination of descriptive and exploratory type of research. It is a descriptive study because it describes systematically the situation (biology research and education) and the problem (incoherent understanding of students). It also provides information and describes the opinion of the students towards systems-based teaching and learning units and also the opinion of the other respondents about different issues dealt with in the current study (Kumar, 2005, Salkind, 2006).

Objective: it can also be regarded as exploratory research because the present project has been undertaken with the aim of exploring the use of systems-thinking in biology education where little is known and where there is a dearth of systematic studies in biology education at university level.

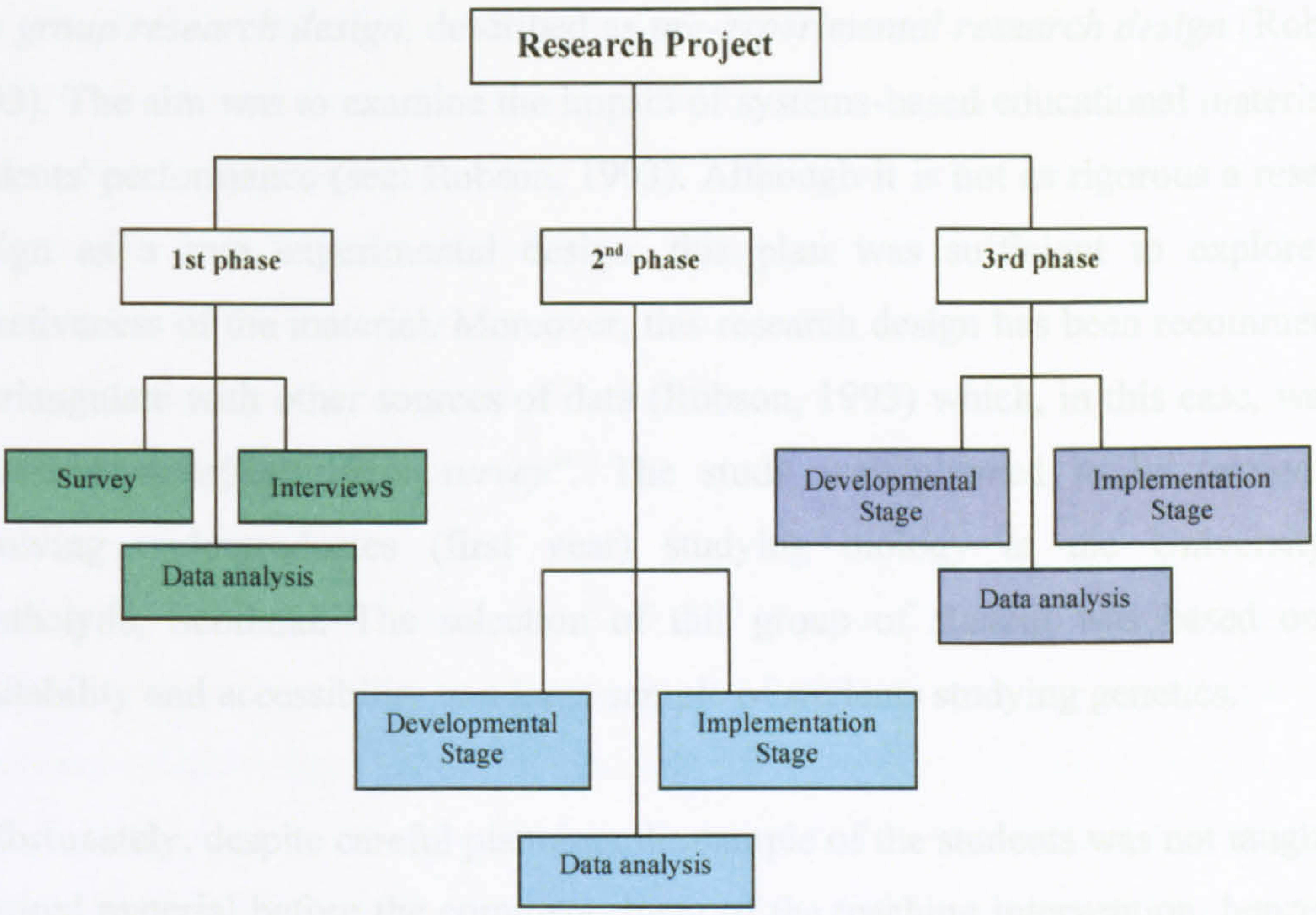
Application: the present study is regarded as applied research because in this exploration enterprise, the findings are anticipated to yield evidence-based knowledge to provide a solution for the teaching and learning problem in biology education (for bringing coherence).

To conclude, the present research project is regarded as a mixed design, exploratory, descriptive and applied.

7.5 Research Plan of the Project

The study began with a clear research plan but this plan had to be modified to address the issues that arose during the study. The details of these issues and description about each phase will be presented in separate chapters, which will provide information regarding methodology, procedures, tasks, analysis and findings related to each particular research phase. Figure 7.2 gives an overview of the research plan and reflects the sequence of the research activities. Each phase is logically linked with the other and evolved from the one on which it is based.

Figure 7.2 Activity diagram showing the phases and tasks involved in the project



The study is an exploratory case study. It has been conducted in three different phases with different samples in different countries, each with specific objectives to be achieved in order to answer the overall research question. An overview of the whole research project is now presented.

Plan for First phase

The first phase was planned as an exploratory phase and was carried out in Scotland (details in chapter 8). The opinions of biology researchers and lecturers, about systems biology, systems-thinking and biology education were explored through interviews. A survey was conducted with the undergraduates (second year) studying biology at a Scottish university, to find out the difficult core areas and topics in the biology curriculum. The findings of this stage determined the way second phase was planned.

Intended and Adapted Plan for Second Phase

The second phase was completed in two stages (fig 7.2). The *developmental stage* involved the development of systems-based educational material while the *intervention stage* used the developed material with the students (details in chapter 9). The initial research design chosen for intervention stage was a *pre-test, post-test one group research design*, described as *pre-experimental research design* (Robson, 1993). The aim was to examine the impact of systems-based educational material on students' performance (see: Robson, 1993). Although it is not as rigorous a research design as a true experimental design, this plan was sufficient to explore the effectiveness of the material. Moreover, this research design has been recommended to triangulate with other sources of data (Robson, 1993) which, in this case, was an *"intervention effectiveness survey"*. The study was planned to be carried out involving undergraduates (first year) studying biology at the University of Strathclyde, Scotland. The selection of this group of student was based on the availability and accessibility to a large sample of students studying genetics.

Unfortunately, despite careful planning, the sample of the students was not taught the required material before the commencement of the teaching intervention, hence, the research design had to be modified. Because the teaching had not been completed in the lecture course, the students were not able to answer the questions given in the pre-test and this made a comparison of pre and post test results impossible. Therefore, the results could not show an increase in performance over the use of a standard lecture course. The research design was modified to a *post test one group descriptive case study.* For this reason it was decided to use the systems-based educational material once more and this decision led towards the planning of the third phase of the project.

Intended and Adopted Plan for Third Phase

The third phase was carried out in two stages as well (fig 7.2). The research activities took place in the Netherlands and Pakistan (details in chapter 10). The systems-based material was refined and developed in the *developmental stage*. A group of biology educationists was approached in the Netherlands. The reason for selecting this group of educationists was their expertise in educational research using the concept of systems-thinking in biology. The initial research design chosen for *intervention stage* was *quasi experimental*. The purpose was to find out the difference between two groups in terms of their performance in the test after using the new teaching material. The quasi *experimental design* is known as 'a close cousin of experimental research' (Salkind, 2006) and is sometimes regarded as the second best choice (Robson, 1993). There are many situations in educational research when it is not possible to conduct true experimental research (Burns, 2000). Generally, in social science research quasi experimental designs are chosen when random allocation of individuals to control and experimental group is not possible (Somekh & Lewin, 2005). Although quasi experimental research design casts a doubt on the internal validity because groups may not be equivalent, yet, the results of such studies are still found convincing (Bryman, 2001).

To carry out this plan, two colleges in Abbottabad, Pakistan, were chosen. The reason to carry this research activity in Pakistan was that the researcher could negotiate access to the biology students within the time period which was available. However, once again, the planned research design had to be modified. Unfortunately, planned sample number dropped markedly because of social events in one college and pending examinations in the other. The study was adapted to be a descriptive case study rather than the quasi experimental case study.

Due to such circumstances the research plan had to be changed and the methodology evolved accordingly. The next chapter describes the first phase of the research project and explains its methodology employed, and also the findings.

CHAPTER EIGHT

Exploratory Phase

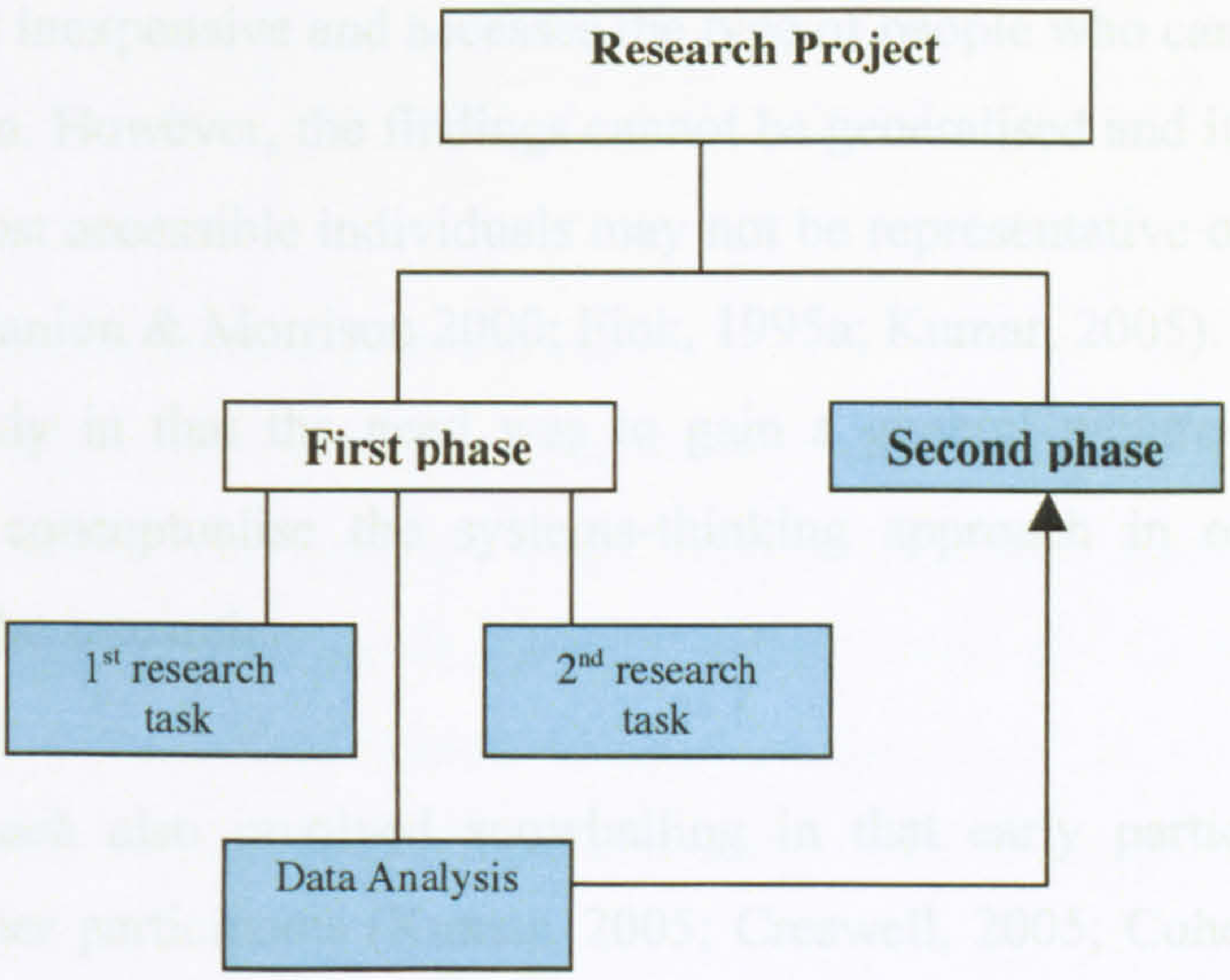
(First Phase)

This chapter explains the first phase of the project. It describes the methodology and the procedures employed for data collection, data analysis and the findings.

8.1 Nature of the First Phase

It was an exploratory phase. Two activities were planned: *firstly*, to explore different aspects of the current research and educational practices in biology; *secondly*, to explore the difficult core areas in biology curriculum for the first year at a Scottish university. Data collecting instruments were selected and prepared, the sample was chosen, respondents were contacted and arrangements were made to collect the data.

Figure 8.1 Diagrammatic representation of the first phase of the research project



8.2 The First Task

The objective of the first research task was to explore the understanding and opinion of biology researchers and lecturers about their:

1. Perceptions of systems biology;
2. Understandings of system thinking ;
3. Opinions regarding present teaching and learning practice of biology.

It was hoped that this would provide a broad picture about the landscape of research and education in relation to biology which, in turn, would assist in the development of biology teaching.

8.2.1 Sample

While the gold standard of sampling in research is often considered to be random sampling, in small scale qualitative studies sampling can be based on criteria, convenience and snowballing. In this case, the criteria involved the inclusion of biology researchers who had sufficient teaching experience and insight to comment on different aspects of biology education at undergraduate level. The sample was convenient because it involved those in two neighbouring universities (see: Gay et al., 2006; Kumar, 2005; Salkind, 2006; Clark, Riley, Wilkie & Wood., 1998). This approach is often recommended when trying to getting a feel for the issues and focusing on particular issues involved in investigation (Robson, 2002). The approach is easy and inexpensive and accesses the type of people who can provide the required information. However, the findings cannot be generalised and it has to be recognised that the most accessible individuals may not be representative of the total population (Cohen, Manion & Morrison 2000; Fink, 1995a; Kumar, 2005). This is not a problem in this study in that the need was to gain a general picture of how experienced biologists conceptualise the systems-thinking approach in order to inform later phases of the research.

The approach also involved snowballing in that early participants were able to suggest other participants (Kumar, 2005; Creswell, 2005; Cohen et al., 2000; et al., 2006, Fink, 1995b; Robson, 2002) who were well versed in their understanding of systems biology and teaching and learning problems in biology. Of course, this approach can lead to a biased sample (Kumar, 2005) but this was not seen as a problem in that the interviews were seeking to gain a picture of the variety of views which existed among biologists rather than to identify for example which might have been the view most commonly held.

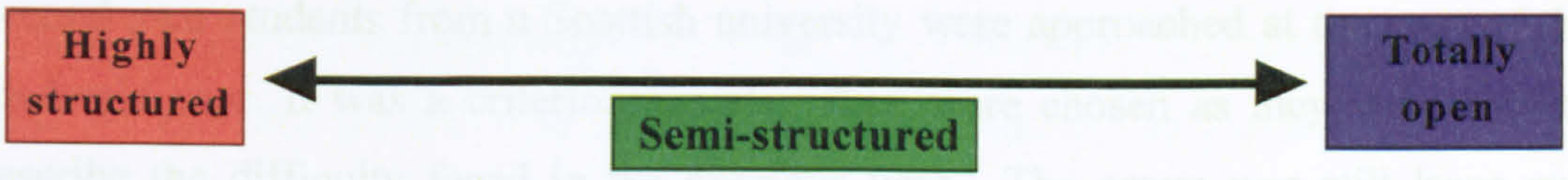
A sample was chosen of eight experienced biology researchers and lecturers, all involved in biology education at university and some of them were involved with systems biology: six lecturers from two universities and two researchers from a cancer research centre. The sample reflected a wide range of specialisms and was diverse in terms of their degree of knowledge, understanding, experience and involvement in biology education (table 8.1).

Table 8.1 Attributes of the sample

Interviewee	Subject Specialisation	University Teaching Experience
1	Pharmacy, genetics	20 years
2	Cell biology, biochemistry	6 years
3	Evolutionary biology	40 years
4	Biochemistry	42 years
5	Environmental science	30 years
6	Bioinformatics	14 years
7	Bioinformatics	6 years
8	Systems biology	4 years

8.2.2 Data Collection Instrument

To gain insights into the issues related to systems biology, systems-thinking and biology teaching and learning, these eight people were interviewed using a semi structured interview schedule. Reid (2003), Robson (2002) and Walliman (2005) have discussed the use of interviews and how these can take several forms. A variety of interview types have been mentioned in the research literature:



These three types of interviews differ in the degree of freedom given to the respondents and the degree of control the interviewer exercises over the conversation.

Interviews have many advantages. They can be a flexible and adaptable way of gaining information, with a wide range of applications. They have an advantage over questionnaires in that the quality of responses can be confirmed by observed body language, and possible misunderstandings can be reduced (Robson, 2002; Walliman, 2005). However, they are time consuming in planning, conducting, transcribing, analysing, summarising and presenting, and are open to the possibilities of interviewer's bias.

A semi-structured interview strategy was adopted and an interview schedule, consisting of a predetermined list of questions and issues to be explored was created. It also allowed freedom to the respondents to expand and extend their answers as appropriate. Face to face interviews were conducted after making prior appointments with the participants. The interviews were tape recorded and transcribed. The interview schedule had three sections consisting of questions about systems biology, systems-thinking and biology education (teaching and learning) practice respectively. A copy of the interview schedule can be found in the appendix (p.353).

8.3 Second Task

The second task was to identify students' perceptions of areas of difficultly in the first year biology curriculum. For this purpose a survey was conducted to identify a possible topic which might be suitable for the development of systems-based teaching material.

8.3.1 Sample

Second year students from a Scottish university were approached at the start of the academic year. It was a criterion sample. They were chosen as they were able to describe the difficulty faced in the previous year. The group was still large and diverse. There were 116 students, 31 males and 85 females, which reflect the typical gender proportion of a biology class.

8.3.2 Data Collection Instrument:

The strategy used for this task was a survey (Robson, 1993, Denscombe, 2003) using the difficulty survey instrument. Surveys have been described as efficient in providing a large amount of data in short period of time with relatively low cost (Robson, 1993). They are often conducted to paint a quantitative picture and can also be used for descriptive purposes. They are used for collecting information on a broad range of subjects (Fink, 1995a, 1995b). This approach has disadvantages as well. Of course, there is no certainty that respondents will take the exercise seriously or will be totally honest, especially if they think there is some agenda or they wish to offer 'desirable' answers (Robson, 1993).

For '*biology difficulty survey*', an instrument used and developed by Sirhan, Gray, Johnstone and Reid (1999) was adopted. The students were presented with the following four core areas of biology curriculum:

Cellular structure and Function
Microbial and Plant Bioscience
Genetics and Molecular Biology
Animal Bioscience

They were then asked to choose two core areas which they thought were most difficult for them. After selecting two difficult areas, they had to express their opinion about their understanding of the subtopic in the selected core areas by ticking the appropriate box. Each topic was marked as easy, moderate or difficult. The descriptions of these three terms was defined for them as

Easy:	I understood the topic first time.
Moderate:	I found it difficult but I understand it now
Difficult:	I still do not understand.

The students ticked the boxes to evaluate their understanding of the topic and were invited to comment on difficulties. However, they rarely used this option. The survey questionnaire was piloted with the trainee biology teachers to check for clarity but this type of survey questionnaire has been known to give reliable results. A detailed study by Sirhan et al. (1999) with a similar sample, showed results which were remarkably similar to the actual difficulties as judged by detailed scrutiny of examination scripts. A copy of the questionnaire can be found in the appendix (p.355). The findings and analysis of the data collected from both the interviews and the survey are now discussed in turn.

8.4 Interviews with Biology Researchers and Lecturers

This section gives an account of the findings of the interviews conducted to find out the opinions of experienced biology researchers and lecturers about three areas: systems biology, systems-thinking, and teaching and learning in biology. Each is now summarised in turn. The transcripts of the interviews were studied carefully and key themes were extracted. In the summary presented here, the respondents have been identified by using numbers.

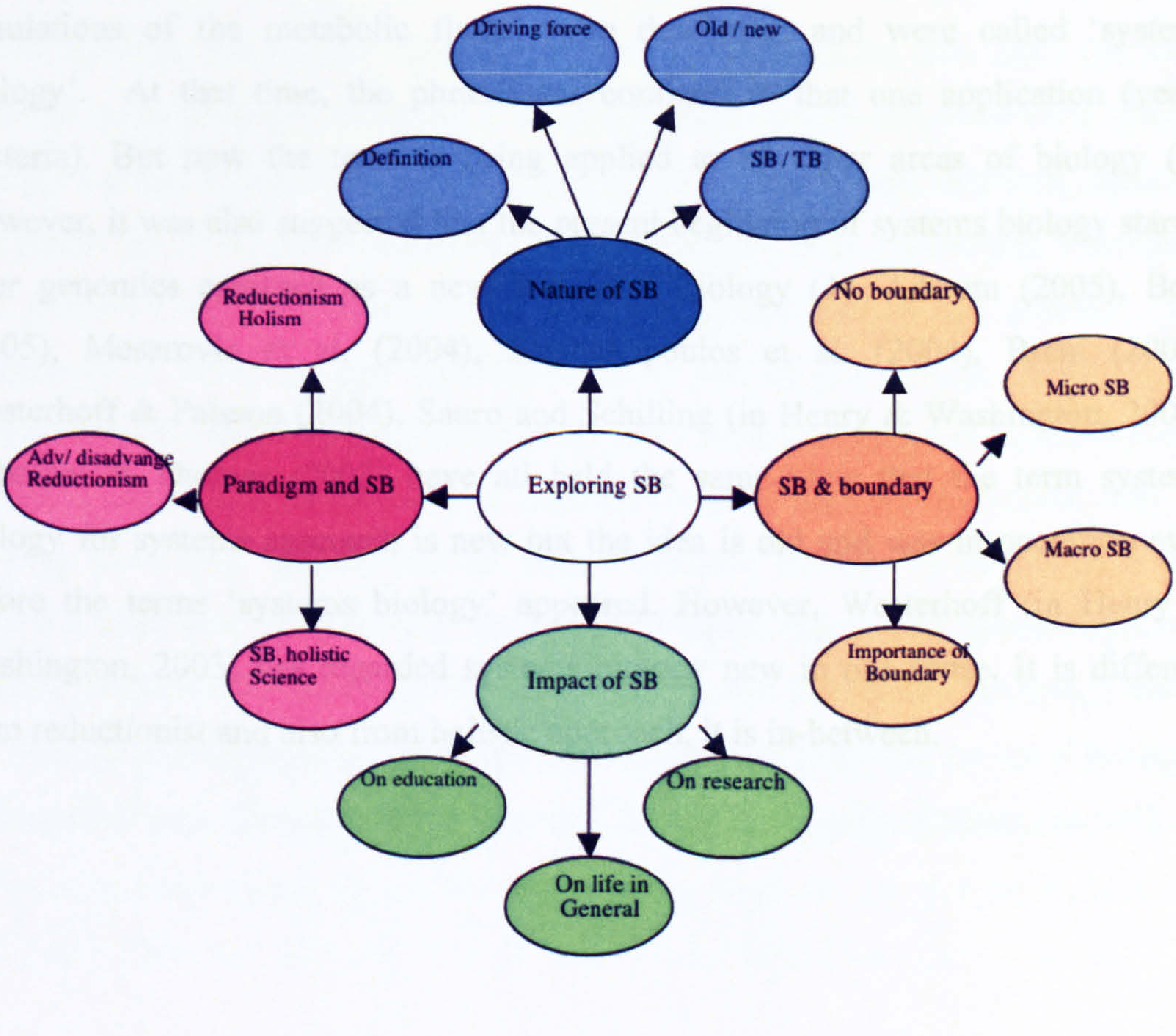
8.5 Exploring Systems Biology

This part of the interview schedule explored four issues related to systems biology:

The nature of systems biology;
The concept of boundary and systems biology;
The paradigmatic debate in biology research;
The impact of systems biology

The sub themes are summarised in figure 8.2.

Figure 8.2 Themes and sub-themes from the interviews



8.5.1 Nature of Systems Biology

Four questions were posed related to the nature of systems biology: being new or old, driving force behind it, its definition and the difference between systems biology and traditional biology. The response to these questions is presented below.

New or Old: Three of the respondents were not familiar with the term systems biology but recognised it under different names. For the others, systems biology was not new. It was suggested that biologists even in the past had a systems approach and were systems biologists without using the name. This approach is what biologists always wanted to do (1, 2). To some, systems biology was an amalgamation of the new and the old. The old part was the idea that living systems were different from the Newtonian bodies (closed systems); and, the new part was the availability of huge amount of data and the way all these data are handled (6, 7).

It was indicated that the term 'systems biology' was coined in late 60s or early 70s. It was applied mainly to fermenting bioreactors where bacteria or yeast were grown in very large quantities to understand how all the metabolic fluxes work. Computing simulations of the metabolic fluxes were developed and were called 'systems biology'. At that time, the phrase was confined to that one application (yeast, bacteria). But now the term is being applied to all other areas of biology (7). However, it was also suggested that the present beginning of systems biology started after genomics emerged as a new branch of biology (1). Aderem (2005), Bork (2005), Mesarovic et al. (2004), Stephanopoulos et al. (2004), Brent (2004), Westerhoff & Palsson (2004), Sauro and Schilling (in Henry & Washington, 2003), Friboulet & Thomas (2005) have all held the same view that the term systems biology for systems approach is new but the idea is old and was in operation even before the terms 'systems biology' appeared. However, Westerhoff (in Henry & Washington, 2003) has regarded systems biology new in one sense. It is different from reductionist and also from holistic approach, it is in-between.

The driving force: The following factors were regarded as driving force behind systems biology.

Driving force behind systems biology

- Grant awarding bodies
- Complexity of living systems
- Huge amount of data
- Realisation to integrate
- Technology

An interaction between the *funding bodies* and research activities was mentioned. It was noted that funding bodies are interested in an interdisciplinary approach; universities take their programmes in the direction where funding is available. An interdisciplinary approach is turning to physics, turning to chemistry (interface biology), and turning to mathematics and computation (systems biology) (1). Moreover, *technology* has been considered a driving force (7). Digital technology and post genomic tools have given birth to enormous amount of information (1, 6) which needs to be integrated, and integration needs professional help and thinking from other disciplines, mathematics technology and computers (1).

These opinions and beliefs of the respondents are consistent with what has been reported in the literature. Abersold et al. (2000), Bork (2005) also trace back systems biology's origin to the development of post genomic technology. Similarly Schilling and Arkin (in Henry & Washington, 2003), Mesarvoic et al. (2004) and Westerhoff and Palsson (2004) regarded it as a technology and data driven science. The *complexity of living systems* has also been as one of the driving force. This is consistent with what Stephanopoulos et al. (2004) and Mesarovic et al. (2004) have described about the complexity. It has been argued that the traditional way of thinking and doing research has not been considered enough. Hence the need of a different approach, of knowing the system, collaboration and interdisciplinary: systems biology (8). Hood and Perlmutter (2004) and Nicholson, Holmes, Lindon, and Wilson (2004) stated that the biological complexity impeded the novel therapies in drug discovery. They see complexity as a driving force and a challenge as well.

Definitions: Four definitions were suggested:

> *'Systems biology is thinking about an organism as a system' (7).*
>
> *'Systems biology is working on cellular signalling system which conveys information from environment and processes it via biochemical reactions in the cellular response'* (8).
>
> *'An attempt to use analytical approach including mathematics to categorise, analyse and perhaps predict what biological system would do* (6).
>
> *"It is mentally treating an organism as a whole trying to understand how the whole thing works. Systems biology is a modelling approach to biology."* (4)

The first definition is a general view of systems biology and talks about the fundamental idea behind a systems approach. It talks about the objects of interests: living organisms. Its object of interests can vary from microbes to macro organisms. Systems under investigation could be a cell, a pathway or an organism (micro or macro). Therefore, the respondents believe that there could be systems biology of microbes, systems biology of a blood clot, systems biology of biochemical pathways, systems biology of cells, systems biology of yeast, systems biology of plants and molecular systems biology and so on (1). The second definition is more specific and narrowed down to 'cellular *signalling system'* which means that systems approach can be applied to any system. However, the latter two reflect the quantitative approach to the study of living systems. They reflect the interdisciplinary nature and the expected outcome of systems biology: prediction. The final definition suggests the general meaning of systems biology by highlighting the mind set behind it. However, at the same time, it is specialised, suggesting the specific activity or approach of systems biology: modelling which indicates the involvement of other disciplines to understand the living organisms.

Almost all of the respondents felt that there was no agreed definition as yet and perhaps there would never be a consensus about it (8). Kirschner (2005), Mack (2004), Bork (2005) and Brent (2004) expressed similar opinions about the vague definition of systems biology. The lack of agreement partly lay in the sheer diversity of biological organisms. As many people have an attraction for systems biology and investigate different aspects of a system. Thus, mathematicians describing the movements of cell consider they are doing systems biology. Other people have come from different directions in bringing different backgrounds to systems biology (1). Thus systems biology means different things to different people. The lack of consensus about its definition was traced to its origin as it was told that it has not evolved slowly (1). The term came first and the field developed later (7). More cynically, it has been remarked that biologists perhaps deliberately keep the definition opaque. It is used as a way to gain funding; confusing those who are not aware of what is involved (4). Similar views have been reported in the literature. Henry and Washington (2003), Liu (2005) stated its different meaning to different people. Lauffenburger has (in Henry & Washington, 2003) argued that systems biology would be defined by what people actually do is productive and effective. Fickett (in Henry & Washington, 2003) mentioned that from now on, in some sense, everything that we do would be regarded as systems biology.

***Systems biology and traditional biology*:** The differences between *systems biology* and *traditional biology* were explored and several points were made. The following were stated to be the characteristics associated with systems biology which are not common in traditional biology.

- Recognition of complexity
- Call for integration
- Predicting the systems behaviour
- Quantification of data
- Modelling approach to biology
- Involvement of formal mathematics
- Data driven biology

Firstly, systems biology recognises the biological complexity and calls for collaboration to deal with it. Traditional biology research rarely admits that assistance is needed to fathom the living system (1, 8). *Secondly,* the wish of systems biology is to describe the whole biology of the organism and to make predictions about this as a system. Perhaps, systems biology has to use many approaches while traditional biology has only one approach (1, 7). This is consistent with what Butcher et al. (2004) stated that systems biology encompasses many different approaches and modes for probing and understanding biological complexity.

Thirdly, systems biology tends to quantify observation while data collection or observation is mostly qualitative in traditional biology. Systems biology relies intensively on computer technology and mathematics for handling the data (modelling approach) while traditional biology is focused on description. Systems biology is interdisciplinary while traditional biology tends not to embrace an interdisciplinary approach (8). *Fourthly,* it was stated that intuitive thinking plays a much higher role in traditional biology while systems biology is more computational based on formal mathematical models and is, therefore, more structured and formal. Traditional biology was also criticised for being unstructured and non formal because of the lack of the involvement of mathematics (8). These opinions are consistent with what Aderem (2005), Bork (2005) and Henry and Washington (2003) talked about the contribution of other disciplines for generating and quantifying data but also holding the enormous amount of it.

Finally it was added that systems biology is driven by the amount of information but traditional biology is driven by hypothesis testing: *'in traditional biology you have a hypothesis of how something works. You set about going and testing hypothesis at whatever level you are dealing with, the whole organism or parts of the organism. But systems biology ... says that if you can get all information ... You should be able to model it. It does not come with any hypothesis at all except that mathematically we can model how does it work'* (4). Contrary to this, Schneider (in Henry & Washington, 2003) believes that systems biology is a hypothesis-based research while to Lauffenburger (in Henry & Washington, 2003) systems biology is a combination of hypothesis-driven and discovery-driven research.

Thus, systems biology is believed by the respondents to be not altogether new but it has taken a new approach to develop the understanding. It involves and invites scientists from other disciplines to take part and assist in the endeavour of understanding the complexity of life, making it more mathematical and interdisciplinary. The vastness of biology makes any agreed definitions difficult.

8.5.2 Systems Biology and the Concept of Boundary

Another question looked at the concept of boundary and systems biology. This issue was raised with the interviewees and two types of boundaries were mentioned in systems biology: *biological boundaries* of the systems and *conceptual boundaries.*

A system can either have a boundary or it may be a system with no boundary at all. It was told, *'in biology, one can deal with different kinds of systems such as single organism as a system, a single organ as a system or whole community of organisms as a systems'* (4). A system can be a unicellular organism or a multi-cellular. In a multicellular organism, levels have been identified which are, to some extent, self-contained and then there are levels above and below (2). For example, these levels can be cell, tissues, organ, organism, community etc. Hood and Perlmutter (2004) also believe that systems biology is an analytical approach which can be applied to any molecules, cells, organs, individuals and eco systems.

Some of the respondents believe that systems biology does not operate with the concept of boundary. There is no boundary in systems biology they claim because, *'it might not necessarily be concerned with the biology of the whole organism'* (1). However, they believed in the importance of drawing a boundary, in order to limit one's investigation (4) because, in the absence of a boundary, *'one will end up modelling and connecting everything with everything which will be completely impossible'* (7). Where to draw a boundary depends upon the question being asked in a particular investigation (8), the wish of the person to limit, and the amount of data one wishes to collect (4). It was stated, *'at research levels very small discoveries are made and research teams tend to discover a little of this and a little bit of that and then gradually build bigger and bigger sum of knowledge'* (3).

The above mentioned opinions of the respondents confirm that boundaries may be natural or mental constructs to put limits on investigation. In this regard, Arkin (in Henry and Washington, 2003) Mesarovic et al. (2004) Westerhoff & Palsson (2004) have regarded genome as a system. Similarly, Butcher et al. (2004) have reported that systems biology has its focus on many organisms from microbes to man.

Nicholson et al. (2004) have regarded human beings as super-organisms which are highly complex systems. Stephanopoulos et al. (2004) stated that cells were previously considered as systems but now systems biology has gone beyond and within the cell to define systems.

8.5.3 Paradigmatic Debate in Biology Research

This included issues regarding the place of reductionism and holism in research, and advantages and disadvantages of reductionism. The views of the interviewees are now summarised.

Both reductionism and holism
- Complement each other
- Had different time of prominence in history
- Both ask different questions

It was suggested that science itself by definition is reductionist. However, both reductionism and holism were considered important in biology research by all the respondents. There was a consensus of the need for both because they complement each other: neither of them works on its own (7, 5, 8, and 4). It was stated:

> *'Reductionism and holism have had different times of being highlighted. History tells that Darwin and all the emerging biologists were in some way holistic biologists. They looked at the organism because they did not have the tools at that time; therefore, they had to look at the whole picture'* (1).

The 20th century is considered a century of reductionism and now in the 21st century there is a period of integration. The cycle of approach appears to keep going depending on the type of sources and resources available and the type of investigation involved.

It was stated that, *'reductionism is also an attempt to understand something but disassembling things allows one to understand only the parts. Therefore it is limited in developing one's understanding about the functional connections between parts'* (8). On the other hand, *'if one has just the holistic approach one can never understand the underlying mechanisms of why something works. Therefore, the holistic approach is limited as well because it lacks in understanding of the underlying mechanisms'* (8). Reductionist and holistic approach both are needed in research because both approaches ask different questions: how something works in isolation and how something works as part of the whole picture (3).

The advantages and disadvantages of reductionism were also articulated.

Advantages of reductionism
- Helps in attaining detailed information
- Gives zeal for discovery
- Provides simple statement of truth

Disadvantages of reductionism
- Oversimplification may lead to lose sight
- Leads to fragmentation

Firstly, the respondents recognised the importance of reductionism to get the detailed information (1) which is consistent with what many reported, recognising the role played by reductionist approach in the progress of biology (Stephanopoulos et al., 2004; Katagiri, 2003; Capra, 1997; Debru, 2002). Secondly, it was told *'the reductionist approach gives you hope that you will capture a kind of an essential part of reality but it always turns up that whatever you have captured is a certain part of reality but it is never clear that you have captured the essential part of reality'* (7). So it keeps the zeal for making further inquires and investigations. Thirdly, it is also necessary *'to get something to be a simple statement of truth and then use that to extrapolate back and make sure that it works in whole systems'* (2).

On the other hand, it was stated that practised in isolation, the reductionist approach has its serious limitations. Firstly, if everything is made too simple by just taking it down to the core elements, one can lose the sight of the context (2). Secondly, *if one is extremely reductionist, then there is uncertainty about capturing anything about reality* (1). However, *'if one is not reductionist at all, then it ends up with completely a holistic picture which is probably very close to religious beliefs'* (7). Therefore, it was told that one has to be somewhere in between these two extremes and there is a belief that systems biology is somewhere in between (7). Westerhoff (in Henry & Washington, 2003) also called systems biology as in-between the two. The respondents agreed that reductionism is appreciated whenever it is needed and scientists know that what they are looking at is not a whole story (3, 5, and 6). This is consistent with what Richard (1999) said that there was always an awareness among the biologists that the knowledge of structure and function of macro molecules is not enough to understand the whole system.

Some respondents strongly believed that systems biology is holistic (5, 8) but some saw it as holistic approach, but only in theory. It was stated *'systems biologists are trying to understand how the whole organism works but the amount of information and complications of studying everything is huge and vast where so many variables operate...it is not credible...* (4). There is a realisation among systems biologists that systems biology is not going to deliver holistic explanation in a short time in the near future (6). Arkin (in Henry & Washington, 2003) also stated that there is a sense in which systems biology is trying to look at the entire system but that is not realistic. Systems biology is just like looking at large piece of system not the complete system. It was also remarked that, '*...we have moved to the second generation of the new generation of holistic approach*' (1) which suggests that the holistic approach is passing from one phase to another.

It was argued that, to some extent, both traditional biology and systems biology are reductionist because being holistic in science, although optimistic, to some extent is naïve (7): *'systems biology is slightly less reductionist or more holistic than traditional biology'* (7). It is a mid-way between reductionism and holism. It was commented that systems biology oscillates between the two poles: towards the holistic pole to find out how the components work together and reductionist in dissecting things and mapping components (7, 1, and 2). Systems biology was regarded as what biologists always wanted to do (2, 1). This opinion is consistent with what Arkin (in Washington & Henry, 2003) has reported. It was also added that, although it is complicated to connect many components together, it can be done if rules are known (8). Both, reductionism and holism are needed in science. One is not possible without the other, consistent with Katagiri (2003), Henry & Washington (2003), Westerhoff (in Henry & Washington, 2003) who all argue that systems biology needs both approaches.

8.5.4 Impact of Systems Biology

The final sub question posed was about the impact of systems biology on three areas: life in general, on education and on research. Opinions varied. Most of the respondents had a positive attitude towards systems biology although negative positions were also observed.

Looking at life in general, it was stated: *'...environmentally may have impact. People understand that everything that happens has impact globally and it goes to the next systems up to the eco system'* (2); *'...it should make us healthier and improve our quality of life in principles. It could improve environment if you are prepared to follow the recommendations that systems biology takes'* (1)

It was suggested that a positive and profound impact would be in the field of health and environmental issues (1, 7). Thus, the expectation for cures of certain health related problems (like a cure for cancer) is very high (7, 1). Henry and Washington (2003) regarded pro environmental action to be one of the expected outcomes of systems biology where microbes would be used as cleaners at contaminated waste site. Voigt (2004) has been reported working on making bacteria that are modified genetically to perform a variety of jobs such as the cleaning up of toxic chemicals and also fighting against cancer cells. The drug discovery and development (Henry and Washington, 2003), health and medicine practice, diagnosis and therapies of human diseases (Westerhoff & Palsson, 2004) has been reported to see the potential impact of systems biology. Similarly the research into the strain improvement to design microbes for maximum product formation and also to design non-natural metabolic pathways to engineer new strains capable of synthesising fine chemical have been reported by Stephanopoulos et al. (2004) and Mack (2004). Although, interviewees believed that systems biology would have an impact on health and environmental issues (1, 2, and 5) there was a realisation that a direct impact in the near future is not expected. Being a very young science, much uncertainty about its hopes to see its tangible effects in the field of medicine have been reported by the interviewees by saying that some of them would be fulfilled and some not in the near future (7). This confirms the situations in the literature where it has been mentioned as a challenge for systems biologists to meet the expectations because there is a lack of practical results so far (7). Stephanopoulos et al. (2004) also hold similar opinion.

Secondly, in the *educational sphere,* the impact of systems biology respondents perceived as challenging (1, 7, 8, 6, 5). There is a realisation that education has to keep pace with the science. It was stated that,

> *'... not very many researchers try to take a kind of synthetic view... the whole approach to PhD investigation in the biological sciences is usually to take a narrow topic and on a particular organism... it leaves people with a narrow view of the whole of biology... it tends to leave to a fragmented thinking '* (3).

This suggests that biology education is not moving at the same rates with the biology research for training the personnel for systems biology. Lack of projects for practicing systems-thinking in academic research projects was identified. Respondents realised that many courses and degrees (Masters and PhD) in systems biology might be developed in the main stream of biology education in the near future. However, they see it as a challenge to design curricula for systems biology. It was asserted that systems biology would be a challenge to teach (8).

Respondents mentioned that a systems biology approach to teaching has to make its way into the school curriculum because the present school curriculum was designed in 1960s and is somehow a reflection of the reductionist approach. It indicted *'what was really important in the 1960s and now there is a need to move from there onwards'* (1). Therefore the impact of systems biology on the school curriculum is required to meet the needs of present and future generations (3).

Interviewees also added that the curriculum content for secondary school needs adjusted (1). Teaching material needs to be developed informed by systems biology to lead students *'to take a thinking view of biology rather than just learning a whole pile of facts'* (3). Thus, *'it would help in affecting students' thinking patterns and also will enhance their understanding if material is presented to them in a systems way instead of presenting it just a collection of facts'* (7).

It was argued that, *'systems biology will provide a tool for teaching systematically, to undergraduates and postgraduates, using software tools to show the effects of different molecules in the system instead of just speaking'* (7). This might be an aid to both teachers and students.

Regarding its impact on *biology research* it was mentioned that systems biology might generate immense data but also promises to organise this huge amount of information (6, 4). Systems biology might open the study of biology for scientists other than the biologists. It was told that systems biology has attracted brilliant people from all sorts of disciplines, winning a name for being an interdisciplinary science in itself. This collaboration could boost the communication among scientists belonging to different disciplines and may also give birth to new mathematics, statistics and new computer science. However, such inter-disciplinarity and communication has put a greater demand on the future scientists to learn the language of other disciplines as well (7, 8). Henry and Washington (2003) have also talked about the potential impact of systems biology on a wide range of biological research involving different disciplines. Hood and Perlmutter (2004), Mesarovic et al. (2004) hold similar opinion.

While this field has attracted funding for conducting research (1, 7), respondents also noted, *'it is sucking most of the funding at the moment'* (4) hence the scientists not involved with systems biology are feeling insecure. It was felt that it could have an impact on research methodology. It could increase quantification, making observations more formalised and organised. Additionally, it might change the mind-set of scientists.

Overall systems biology was perceived in both positive and negative ways. Two interesting analogies were articulated regarding the impact of systems biology. Firstly, *'systems biology is going to have impact on the society on the same scale as the atomic bomb had .... Probably, will have profound effect in the developed world in the G8 circle...not in the developing world'* (1). On the other hand, systems biology was like the children's story:

> *'The emperor's clothes'... 'Systems biology is a bit like this. It's something everybody is going wild about now because it's a very nice idea but actually when we clear away the curtains and look through and see what is behind it. It's a complete mess. It is really going to be a tremendous challenge to get anything decent out of systems biology research'(4).*

However, in spite of the problems and challenges, systems biology has been looked at very positively with hopes of cures for the environment and health issues; an aid as in providing tools for teaching biology and encouraging collaborative research work in the research area.

8.6 Systems-thinking

The second part of the interview explored views and beliefs of the respondents about the concept of systems-thinking: definition of systems-thinking and the nature of systems-thinking. Their views on each of these aspects are now summarised:

Of the eight interviewees, only three were sufficiently familiar with the term systems-thinking to provide some kind of definition:

> *"Systems-thinking is thinking about certain part of interest and seeing it as a particular system and each of the part are related and describing the relationship between these components and hope by describing these relationship between these components you are able to elucidate the working of the whole... It is a complicated way of thinking...Systems-thinking is thinking about the communal results of a particular action or a set of action" (7).*

> *"Systems-thinking is attempting to put rigour, mathematical testable frame work into the observation that we make on the whole organism and their interaction" (1).*

> *"A way of putting things into context...taking things apart and putting them back together is complementary thing. Nobody can be a systems thinker without being a reductionist first, because you have to knit the pieces of information to gather, and if you do not have them you can not put them together" (2)*

The above mentioned descriptions are different approaches to defining systems-thinking. The following is the summary of these perceptions and descriptions:

Systems-thinking as a

- Process of developing understanding
- A set of rules to study a system
- Analysis and synthesis of a systems
- Purpose to know how the system works
- Product/ practice of making quantitative observations
- A way of thinking
  - *Complicated way of thinking*
  - *Long term thinking*

Similar types of views have been noted in literature. People have different views and opinions about systems-thinking. To Richmond (1994), systems-thinking is a paradigm and a learning method; to Forrester (in Senge et al., 2000) and Mandibach (1989), it is a modelling activity; to Hogan and Weathers (2003), it is habitual thinking strategy to relating objects and information; to Dorner (in Ossimitiz, 2000), it is sound reasoning; to Smith (2003), it is a conceptual frame work to view the world; and to Senge (1990, 1993, 2006), systems-thinking is a discipline, a frame work, a set of principals and a set of specific tools and techniques.

For those who had not heard the term, a brief explanation of the meaning of systems-thinking was given, stating that the whole is larger than the sum of the parts and the need to look for the links and connections in order to create a more holistic understanding. They all agreed that it is not a new way of thinking even if the term was new:

> *'It is an old trend in philosophy ...' (7); 'People were always systems thinkers without calling them...' (1); 'Scientists always have a synthetic view...they always reveal how the world works...' (3); '... is just a fancy new term" (2); "A repackaging of the old ideas' (6).*

Respondents indicated that systems-thinking is not a novel idea but re-emergence of an old idea under a new name. Consistent with this, Scheetz and Dutton (in Senge et al., 2000) viewed it as an old way of thinking. However, the need for it in this century has been highlighted by many because of increasing complexity and global interdependency (Richmond, 1991, 1993, 1994; O'Connor & McDermott, 1997; Senge et al., 2000; Smith, 2003; Hogan & Weathers, 2003; Chekland & Scholes, 1990). Similarly, its need has been reported by Knipples (2002), Verhoeff (2003) for developing understanding and learning biology as well.

In seeing systems-thinking as an ability, three different opinions were voiced. *Firstly,* the majority of the respondents saw it as a high order ability which has certain requirements; the information and cognitive ability to link and connect; both of these elements are important because mere information does not work. One needs to connect things which need to be known (8). *Secondly,* respondents saw system thinking as an ability which everyone has in varying degrees (2, 3). '... *Just like the other abilities, level of systems-thinking ability also varies in the population from person to person. Some people are better at it than the others'* (2). *Thirdly,* to some systems-thinking is not necessarily a high order skill or general ability but it is what comes from experience (6). *'It requires a person to be able to take a broad overview in order to be a systems thinker. It is a kind of thinking, some people find it easy and others find it very difficult'* (4). Richmond (1991) relates systems-thinking to *'squinting'* (with your mind) to see relationships rather than mere objects. He further argued that squinting takes effort and energy more than simply opening eyes and looking at the object. The effort and extra energy requirement have been regarded as impediments by Richmond in getting used to this way of thinking. It can be argued perhaps people find it difficult to be a systems thinker because of this extra effort and energy needed. Hogan and Weathers (2003) called systems-thinking 'mental taxing' in keeping track of a number of elements and their relationships at the same time.

Two abilities were seen as important by the respondents for systems-thinking: the ability to take systems apart and then put them back together. For some, these are preferred ways of thinking: *"there are definitely people who like to take things apart and there are definitely people who want to put things together... some people do not like taking things apart. They like looking at whole systems... '*(2). It was also added: ' *...People have done it before but most people do not do it and that is the problem'* (5). *'Perhaps those who do not get involved with it find it difficult'* (4). Thus, it seems that four factors contribute towards systems-thinking: having the *information,* the *cognitive ability* to bring it together, *willingness* to do it and *experience* of the kinds of processes involved. Hence, systems-thinking can be thought of as a set of abilities. Similarly, Dorner (in Ossimitiz, 2000, 2001), Hogan and Weathers (2003), Bereiter (in Hogan & Weathers, 2003), Richmond (1991, 1994), Senge et al. (2000) regarded systems-thinking as a set of abilities, continuum of activities and a suite of competences.

Almost, all of the respondents agreed that it is a teachable skill: most things can be taught; thus, people can be taught to think in this way as well (5). People with abilities can demonstrated their value and lead others to think similarly (1). However, one lecturer with more than 40 years of biology teaching experience, stated that,

> *'We do not encourage systems-thinking enough...Systems-thinking is an educational challenge...one of the weakness ...about some biology or any science that is taught at school level is that it is based on just a body of knowledge'* (4).

This statement reflects the idea that systems-thinking is something which is not part of educational practice nor is it promoted. Additionally, it was considered that a type of approach to teaching encourages that particular type of thinking: different approaches for teaching biology produce different kinds of students and thinkers (4). Respondents believe that pedagogical approaches can shape the thinking patterns of the learners and society. Richmond (1991) suggested educational systems as having the best potential for introduction and on a large scale development of systems-thinking. He argued that our educational system has conditioned us to analyze, to decompose and to attend to the details of each part, and less time and effort has been devoted to practice integration for the whole. It was suggested that it would be difficult to give formal lectures on systems-thinking (8). In the light of this brief description following is the summary of the nature of systems-thinking according to the respondents' views.

Summary of the views about systems-thinking

- General ability
- High order ability
- Preferred way of thinking but not by all
- Perhaps a difficult way of thinking so not many people engage in systems-thinking
- Teachable skill
- Systems-thinking as an educational challenge
- Systems-thinking not encouraged in education

8.7 Biology Education

This part of the interview covered four areas of biology education: difficulties in biology education, students' understanding of biology, teaching approach to biology at university level and improving biology education.

8.7.1 Difficulties in Biology Education

Respondents talked about the difficulties associated with teaching and also the difficulties associated with students' learning. A number of areas of biology curriculum seem difficult for the students, such as thermodynamics and energetics population genetics, methods of recombinant DNA technology, cell behaviour, ethics, biomechanics, biochemistry, energy metabolic, and genetics. Genetics has a reputation as a very hard area of biology to learn (1, 2, 7, 5, and 3).

Difficulties associated with teaching biology: A summary of the difficulties identified by the interviewees in teaching of biology is presented below.

Summary of difficulties associated with biology teaching

- Too much information available and hard to decide what to teach.
- Dynamic nature of the subject
- Keeping pace with the incoming information
- Large and heterogeneous classes of students
- Evoking the zeal and motivating the students
- Too much technical vocabulary
- Teaching with systems perspective (potential future problem)
- Complexity of the subject

All the interviewees felt it as a challenge to teach biology. It has been regarded as a vast subject: '*there is far too much biology available and biologists at the university level struggle to prioritise what they need to teach, keeping in view the older* *fundamental concepts while also incorporating the new material* '(1). The dynamic nature of the subject has also been felt as a challenge where the academics have to be honest in imparting the information. What is considered right information today about something might be discarded by research tomorrow. For instance, according to Stephanopoulos et al. (2004), there is a common misconception that the genomic project and accompanying analysis are almost complete. However, the recent results have demonstrated that genomic maps are continuously updated by discarding or adding genes, proteins and new bimolecular interactions for pathways that were considered well understood. It was reported that it is not like mathematics where you can deliver an old lecture about theorems and formulae. To keep pace with the advancement in biology knowledge has been found difficult (1). The technical language issue has also been pinpointed as it was stated: *'they can not get their head round the terminology ... if they do not understand the language, they can not stitch anything back together'* (2). It was identified that the diversity of students backgrounds in biology and huge classes in higher education (especially at lower levels), with students having no prior qualification in biology along with those with excellent qualifications make it hard to provide a sort of teaching which would be suitable and challenging for both the groups (1,3). Similarly, it was noted that what academics find interesting and want to promote as their subject might not be as interesting for the students: what is being taught to them has to be *shown* to be interesting (3). The reported problems associated with biology teaching are consistent with what has been reported by Tunnicliffe and Ueckert (2007), Delpech (2006) and by Tunnicliffe (2006).

It was noted that,

> *'There is a great problem in teaching genetics which we have not faced yet and that is a systems issue because we are still teaching genetics with somewhat reductionist approach...we need to...understand that there is not one component, two component or three components which is the genetic approach, it is 'n' components and this is where the systems approach come in... we are not and... students are not ready to do that either* (1).

The 'n' component in the statement reflects the complexity of the subject but also the limit of human mind to take things in. Apart from this, the following comment is quite revealing:

> '... *Teaching biology is a collection of facts and phenomena. It is quite easy to teach but if you are trying to teach people the deeper problems in biology, it is difficult because most of the teachers do not understand what is happening either... we can put a label on it but it does not mean that we understand how it works. We know something about how it works in terms of molecular terms but we do not exactly understand how it works'* (7).

Delivering factual knowledge has not been found difficult; however, teaching for understanding is something which is much more demanding. This very honest statement reveals much about the complexity of the subject.

Difficulties associated with learning biology: A summary of the interviewees' opinions about difficulties associated with the students' learning is presented below.

Summary of difficulties associated with biology learning

- Too much terminology
- Involvement of chemistry and mathematics
- Microscopic nature of genetic phenomenon
- Problems of linking information from cellular level to organism level
- Lack of logical reasoning
- Misconceptions about the genetic concepts
- Lack of organising principle

Difficult aspects for students include polygenic issues in genetics: di-hybrid and tri-hybrid crosses. The reasons behind this were suggested as lack of engagement in problem solving, lack of mathematical ideas and understanding about probability; additionally, students were thought not good at logical deduction at this stage (1, 3). To conceptualise the outcome of genetics is difficult because it is needed to connect the outcome at the organism level to that at the gene level: '... *what is happening at the genetic molecular level. They have trouble with it and that is where the problem is'* (2). The microscopic nature of genetics has also been noted by some making it difficult to understand (1, 3). Apart from genetics, biomechanics have been reported hard because of the involvement of mathematics (5). Biochemistry is difficult because students are not well prepared in chemistry and are not very good at calculations (4). It was also pointed out *'the lack of principles, to some extent, as compared with the other sciences, is what makes biology difficult to learn because each little factor becomes a principle and it does not help in organising thoughts and mind'* (7). Except for the 'lack of organising principle' all the other difficulties mentioned by the interviewees have been well documented in research literature. The detail has been presented in section 5.4.

8.7.2 Students' Understanding of Biology

Students' understanding of biology was also explored. It was unanimously accepted that, when students come to the university they have fragmented understanding and almost very little sense of connectedness of biology domain (1, 2, 4). Modell et al. (2005) have reported that students have many misconceptions. They also reported various reasons for these misconceptions (summarised in section 5.4). The interviewees referred to school experiences.

Firstly, it was pointed out that biology at school level is limited in its coverage *'... it does not encourage to think about biology as a kind of whole phenomena'* (3). Secondly, it was suggested that the teaching approach focuses on learning and memorising facts and *'...it is not thinking as a scientist... this does not promote scientific thinking'* (3). Thirdly, assessment was also discussed as a factor influencing students understanding. It was considered that assessment does not develop thinking either because *'they have been substantially trained by their teachers to pass examinations and not really to understand'* (1). Furthermore, it was added that assessment has largely moved away from writing essays on topics which needs to draw knowledge from a variety of different areas towards ticking boxes in multi-choice questions. Such assessment encourages them to learn 'in boxes' or in isolation. They learn to pass the test and not to understand (1, 4, and 5). This type of assessment does not encourage thinking in terms of linking and making connections, perhaps leaving fragmented understanding.

However, a lecturer with a very long teaching experience (40 years) made it clear by saying: '*...they come as if it were incomplete in their biological training. Our job is to try over the four years to make it much more complete. We try to deliver knowledge and understanding in a variety of different ways ... lecture, discussion, tutorials, essay writing and research project*' (3). This statement reflects the enthusiasm and sense of responsibility of a committed teacher. The students have just started their journey of learning about this vast subject of biology. They are in the process of collecting information and to make sense of it. Hence, they will need guidance and time to think it through.

This effort of the biology teachers at university level was commended by a lecturer teaching postgraduate students who stated: '*University courses must be teaching interrelatedness to quite a large extent because the students who come to do the postgraduate degree seem to have understanding*' (6). It can be inferred then that this journey of transition is gradual from fragmented understanding at the time of entry in university to much better understanding at the time of graduation. It is unfair and unnatural to expect a big leap in short time. Time, experience and enough information and understanding make them move from fragmented knowledge to a more holistic understanding. University education is a transition period moving from fragmented understanding.

8.7.3 Teaching Approaches in Biology at University Level

Some of the quotes of the respondents regarding the teaching practice at the university level are presented below:

> *'The way you teach depends entirely upon what level of students you are teaching. The teaching skills and the things you have to do when you are teaching first year biology students is completely different from those you teach who are in their final year of study' (3).*
>
> *'Biology teaching is pretty fragmented in the early years... serious and quite successful attempt to integrate all towards the end of 3rd year and 4th year' (1).*
>
> *'With a final year students, the course we teach is almost like seminars. The teaching is interactive... a lot of work is, giving them scientific papers to read... to understand...to discuss and to give presentation about them. So you are actually*

> *training them in basics skills required to be scientists while you are providing information... whereas at level one, you are teaching huge classes... almost impossible to interact... it has to be almost like a theatrical performance to keep their interest, to keep their imagination and to explain with not too much detail how certain part of biology works, why it is interesting and why they should study it. It is really trying to lay the foundation of interest' (4).*

> *'For the students to be able to learn something. It has to be broken down for them but one should always try to put a bit that is holistic at every level... and should go together... when we go up to 4th year, it is all about links and connection, very little new material is in the final years and what we do, trying to give them the same information they gained from the first three years and try in a different context' (2).*

These statements reveal much about the teaching approach. First of all, in the early years (1st & 2nd), although there is an element of knowledge and then an element of understanding where the things are allowed to put together, the teaching approach's emphasis is on the delivery of the subject content, factual knowledge (1, 2). It was pointed out that this emphasis was conceptualised essential to let students have enough information to connect. As far as the assessment at 1st year of university is concerned, the method of assessment was reported to be reductionist because the assessment questions at this level are mostly simple multiple choice items. The use of this assessment tool has been traced back to problems of big class where such types of evaluation allow assessing maximum students in minimum time (5).

Secondly, it was claimed that in the later years (3rd and 4th year), there is a serious attempt to integrate the content of biology and students were thought to interconnect and integrate ideas (1, 5). It was claimed that this sense of connectedness can be picked up through their examination papers and written assessments (often essays) which act like a lens through which *'they can be seen dipping the paint brush in different colours as they begin to pick material from different courses to answer and start connecting them'* (1). This intra-disciplinary change in students' thinking has also been associated with the type of assessment: '*as questions are asked differently they begin to think differently'* (5). It suggests that the type of question asked might mould students' thinking. In this regard, Smith (2003) has argued for the importance of asking relational questions for developing deep understanding. It was suggested that there is a need *'to have a complete spectrum of assessment to ensure that* *students just do not have particular knowledge but also get them to think across the boundary and draw in answers from various parts of other courses'* (4).

The interviewees appreciated that different areas of biology required different approaches and that not all is reductionist: for example the teaching approach to biochemistry and molecular genetics was felt to be reductionist because of the nature of the area but then for animal physiology it has to be more holistic (2); however, before being holistic the teaching has to be reductionist to let students see the components and then how to put them back together. It was added that in order to synthesise it is important to disassemble first to know the parts (2).

The description of the respondents' opinions about teaching approach at university level reveals that learning process makes progress in two stages: knowledge acquisition stage and knowledge integration stage and, for both stages, different approaches of educational practice are needed.

8.7.4 Improving Biology Education

An 'always room for improvement' attitude was observed regarding biology education from all the interviewees. In this regard, students' attitude towards biology, biology curriculum as well as assessment methods were the main issues addressed.

Regarding the content of the school curriculum, it was suggested that the content of the curriculum should be determined and linked with the aim of what one wants to teach to the students: for example the mechanism of some phenomena or the importance of that phenomena. It was stated that, at some stages of learning, actual components are not important because some concepts can be understood without or with small number of bits as well; one needs components when one wants to make sense of the mechanism (2). For example it was argued that students come to university with a confused mind about the mechanism of transcription. It was pointed out that at school level, all that is needed is to make students understand just the importance of phenomena. At university connectivity can be encouraged by requiring them to join things up (2, 1, 3). Consistent with this, Chen and Stroup (1993) have also reported that it has to be decided when to teach the anatomical and the dynamic aspects of a system. Tunnicliffe (2006) has also mentioned the importance of structural and functional aspects of understanding.

The respondents identified that the curriculum at university level can be improved in terms of bringing integration (1). For example, it was said that there is need to marry organism biology with molecular biology to make biology more complete (3). Apart from intra-disciplinary integration, it was realised that what is needed to make the biology teaching more interdisciplinary is the teaching of numerical skills: mathematics and statistics. They suggested that it was not best to have this taught by biologists: *'it is a potential disaster to just have people who study biology because they are not good at mathematics ... need to choose people or persuade people to do biology with different ranges of abilities'* (6). Moreover, assessment was also pinpointed as needing an improvement. A need was realised to use a broad spectrum of assessment because presently assessment (mostly simple multiple choice questions) is driven by staff students' ratios, at the first year at university, because it is not possible to check large number of essays (5, 3, 4). Less time consuming and effective way of assessment has to be looked for which also could encourage students to think in a holistic way.

The opinion was expressed that students need good attitudes towards learning: *'students' attitude towards learning biology is something needed to work on in terms of engaging themselves. Doing more, empowered and responsible for their own learning which is not easy... it comes from school where they are not empowered'* (1). It was also added that a broad spectrum of attitude towards studying biology is observed among students, ranging from very hard working to spoon-fed. Respondents believe that much can be traced back to school education where '*they are forced to work and, in lots of ways, spoon-fed ... teachers help them a lot in learning specifically for examination ... when they come to university there is no one pressurising them to work and we expect them to be mature enough to come and want to do it ... a significant number of students find that transition difficult'* (4). Students are felt not to take responsibility for their learning and, thus, it is needed to empower them so that they can take responsibility for their own learning (1, 4, 3). However, it was also said *'when they come to 3rd year, they become quite enthusiastic'* (5). As their learning progresses so their attitude towards learning changes gradually or vice versa. Above all else, it was noted that, *'the important thing is that the teachers are enthusiastic and that enthusiasm comes over to the students'* (4). Overall, it has been felt that it is needed to bring improvement in the assessment methods and also students' attitude towards their own learning by making them responsible for it.

8.8 Summary

A summary of respondents' beliefs and opinions regarding systems biology, systems-thinking and biology education is presented now.

Systems biology was described by the respondents as a new term but with the old fundamental core idea that the whole is bigger than the sum of its parts. They reported it as more holistic (not completely holistic but it is a mid way between reductionism and holism), quantitative and interdisciplinary involving sophisticated technology. The lack of agreed definition was identified by the interviewees. It was stated that the reductionist approach to study biology still has place in systems biology but its position is more balanced; systems biology aims at studying non-linear causality. It is expected that outcomes from systems biology may make a considerable impact on life. However, biology education has to keep pace with the fast moving changing practices of biology research: academic researchers have to be trained and engaged in projects which involve a systems view. Designing courses for systems biology has been reported as a challenge because it is a young interdisciplinary science which has and will embrace other disciplines.

Systems-thinking has been regarded as general as well as higher order ability by the respondents. It has also been talked about as a set of abilities involving knowledge, cognitive ability, willingness and experience. It has been viewed as a complicated way of thinking; hence many people have been told avoiding it. Thus, it was claimed that such way of thinking is not preferred by many people. It has been considered as a teachable skill, at the same time it has been pointed out that such thinking is not encouraged in schools. It was identified that the emphasis needs to be put on providing opportunities and encouraging students to practice this way of thinking. It has also been signalled that the approach of teaching shapes the thought pattern of the students. Thus, it can be inferred that systems-based teaching may be able to enhance systems-thinking.

Genetics has been reported by the interviewees as a difficult subject for biology students to learn. Different reasons have been associated with it such as making links between the observable phenomenon to the molecular happenings, the involvement of mathematics and chemistry, the microscopic nature of the subject matter involved, lack of logical thinking among students, abundance of terminology and abundance of principles which does not help learning in an organised way. It has also been found difficult to teach biology because of the difficulty of keeping pace with the information, dynamic nature of the information and also because of the huge and heterogeneous classes. Teaching genetics with systems perspective, which is not part of the teaching practice at the moment, has been reported as a challenge for the lecturers.

There has been a strong agreement about students' understanding as fragmented in the first two years of university; however, more holistic thinking has been reported as developing during later years. The change has been attributed to a number of factors such as teaching approach, assessment, experience, maturity etc. The teaching approach at university has been regarded as somewhat reductionist in the first two years but this approach has been considered as a necessity and preceding important phase before one can become systems thinker or holistic thinker.

Possible improvements in biology education included the need of having an intra-disciplinary and interdisciplinary curriculum, bringing changes in assessment process and empowering students to take responsibility of their on learning process. It has been suggested that the present curriculum is not reflection of the current biology research practice and, therefore, is not catering for the systems biologists.

The information gathered through these interviews such as the changing situation in biology research and the expectations from the formal biology education, the need of systems-thinking as a scientific literacy, genetics as the difficult subject for students to learn, is consistent with what has been reported in the literature by and large. All this information provided the basis for proceeding further in this study. The next step taken was the conduction of a survey to find out the difficult core areas and topics in biology curriculum from the students' perspective. The findings of this survey are presented in the next section.

8.9 Outcomes of 'Biology Difficulty Survey'

A survey to find out the most difficult core areas in biology curriculum was conducted with 116 students (73% girls, 27% boys). Firstly, given four broad areas of study they had undertaken in their first year, students were asked to pick the two most difficult. Table 8.2 summarises the findings.

Table 8.2 Percentage selecting core areas as difficult

Core areas in biology curriculum	% Choosing 'Difficult' N= 116
Cellular structure and Function	41
Genetics and molecular Biology	69
Microbial and Plant Bioscience	66
Animal Bioscience	20

Two areas stood out as regarded as much more difficult: genetics and molecular biology; microbial and plant bioscience. There was no statistical difference between the choice of boys and girls. The finding of difficulty associated with genetics learning is consistent with what the biology lecturers reported (section 8.1) as well as many other studies (see section 5.2).

Secondly, students were given a list of sub-topics in the area of genetics and asked to indicate whether they found these easy, moderate or difficult. Those who indicated moderate or difficult were combined to give a category described as 'not easy' and the data are shown in table 8.3. Four subtopics were noted as most difficult by the students:

Problem solving: Examples of genetic mapping and epistasis.
Mapping genes in human and gene interactions
Chromosomes, DNA and jumping genes
Evolution, gene shuffling and humans

Table 8.3 Difficulties with sub-topics in genetics

	Subtopics in genetics and molecular biology	*E (%)*	*M (%)*	*D (%)*	*M+D (%)*
1	Classical genes and their inheritance	36	55	9	**64**
2	Genes, Cells and Chromosomes	48	50	2	**52**
3	Evolution, gene shuffling and humans	26	65	9	**74**
4	Problem solving: use of Pun net square	45	46	9	**55**
5	Chromosomes, DNA and jumping genes	21	65	11	**76**
6	implication of genetics for human health	35	60	5	**65**
7	Mapping genes in human and gene interaction	19	65	16	**81**
8	Problem solving: Examples of genetic mapping and epistasis	13	64	23	**86**
9	DNA: the genetic code and its role as an information base	35	60	5	**65**
10	The chemical structure and replication of DNA	40	54	6	**60**
11	Mutation and DNA	36	54	10	**64**
E = Easy; M = Moderate; D = Difficult; M + D = Moderate plus difficult					

Looking at the list of difficult sub topics, *'chromosome, DNA and jumping gene'* was selected as the basis for developing teaching material based on systems-thinking. Although this topic occupied the third position, it was selected because it was suitable for a systems-based approach. The time of year when this topic was to be taught was appropriate for the development of new teaching material. The focus of the teaching unit was then narrowed to concentrate on *jumping gene* because this specific topic lent itself to the consideration of many levels naturally.

Although students were also given freedom to say why they thought a particular sub topic was difficult for them, but this part of the survey was ignored by the students. Using the findings of this phase, the second phase of the project was planned. The design of this phase is presented in the next chapter.

CHAPTER NINE

Developmental and Intervention Phase

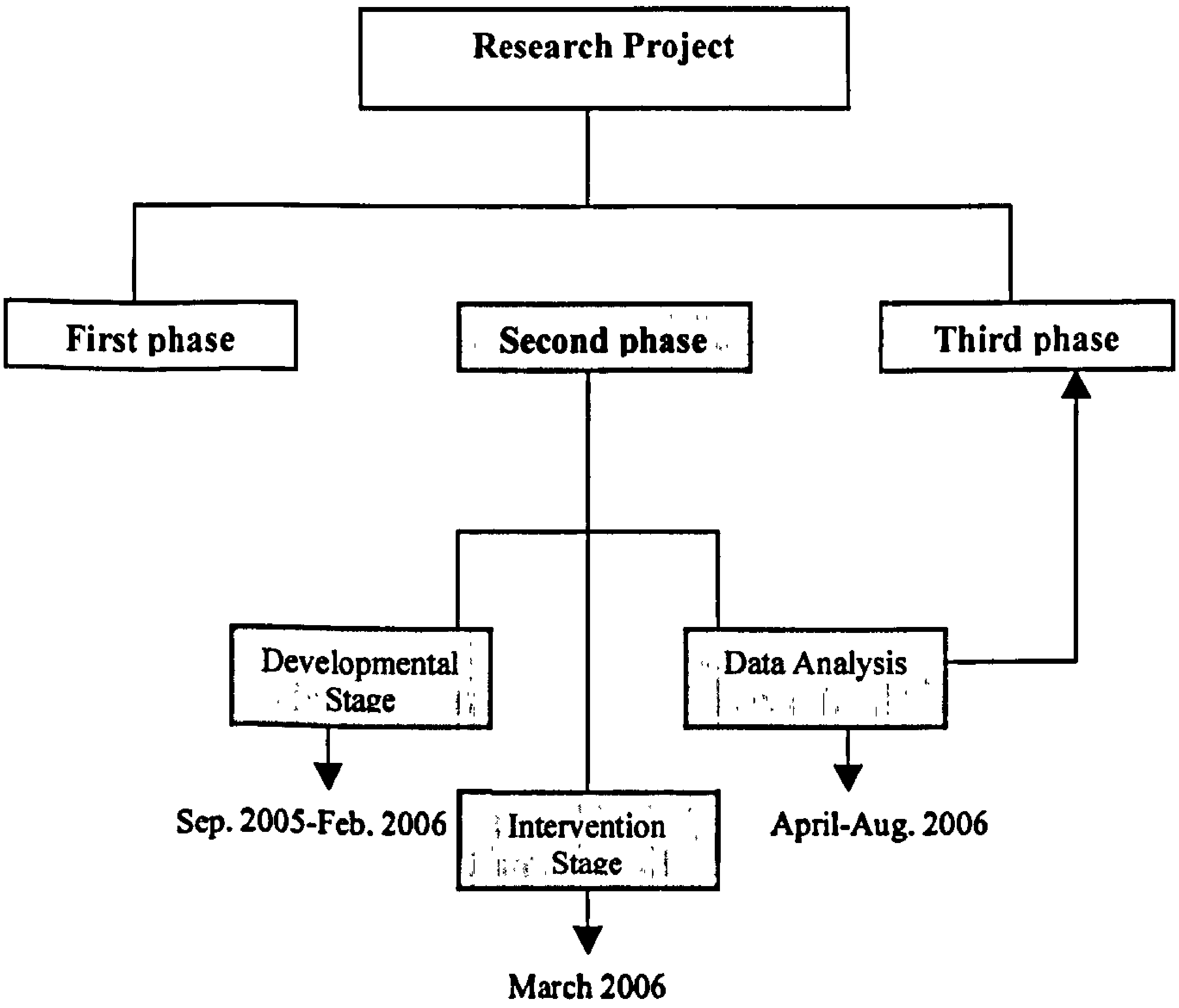
(Second phase)

This chapter presents the description of the second phase of the study, explaining the two tasks, their nature, methodology and the procedures adopted to accomplish them. It also presents the analysis and findings.

9.1 Nature of the Second Phase

The specific objectives of this phase were, *firstly*, to develop and use systems-based teaching and learning material: to use systems-thinking as an educational tool. *Secondly,* to explore its impact on students' learning and students' attitude towards systems-based material.

Figure 9.1 Activity diagram for second phase of the project.



The developmental stage involved the creation of new teaching material (fig 9.1) and also the development and selection of the other data collection instruments: two surveys and two performance tests and how all these were used.

9.2 The Developmental Stage

The outcomes from the interviews with the biologists (chapter 8) indicated the present practices, needs, and challenges which biology education is facing and thus highlighted the possible place of systems-thinking in biology education. In the light of the outcomes from the biology difficulty survey, the topic 'phenomena of transposition' (jumping gene) was selected to develop a self contained package of systems-based teaching and learning material. The material included three elements: *systems-based reading materials*, *systems-based models* and *systems-based activity sheets.*

It is essential to clarify here the meaning of systems-based teaching and learning. The notion of systems-thinking has been employed for structuring and designing the units. The notion of systems-thinking was incorporated in the units without any formal introduction of systems-thinking to the students by the teacher. But the elements of systems-thinking were mentioned explicitly in the teaching and learning material.

Before explaining the nature of the systems-based educational material, it is appropriate to present an operational definition of *systems-thinking as an educational (teaching and learning) tool* adopted for the present research project.

9.2.1 Operational Definition of Systems-thinking as an Educational Tool

Systems-thinking is known as a high order thinking skill and is described as an abstract dimension of cognitive abilities. Being an abstract dimension, it can be considered as a construct: an abstract trait that is only presumed to exist in the mind of the person but cannot be measured directly (Sutter, 2006; Gay et al., 2006). In spite of this characteristic, educational research commonly deals with such complex abstractions.

The abstract quality of constructs makes it important to define a construct in such a way that makes it measurable and observable. For this purpose, presumed indicators of the construct should be identified in order to grasp the presence of the construct.

Such indicators are referred to as the operational definition of the construct. Thus, a construct is an abstract ability which can be opertionalised by identifying overt manifestations: both observable and measurable. When constructs are operationally defined, they become variables. Of course, there could be many different ways of defining a construct, and comprehensive, well-defined operational definitions do not exist. Some may be more appropriate than the others. There is simply no perfect way to identify or define a construct in an absolute way (Sutter, 2006; Gay et al., 2006).

Keeping in view the importance of operationalising the constructs, *systems-thinking as an educational tool* in the context of 'the phenomena of transposition' was defined for the current project. The operational definition of systems-thinking as a teaching and learning tool stemmed and emerged from the descriptions of systems-thinking reported in other research areas (O'Connor & McDermott, 1997; Ossimitz, 2000; Kali et al., 2003; Knippels, 2002; Verhoeff 2003). All these authors have provided definition of systems-thinking as a cognitive competence but none has given the definition of systems-thinking as a teaching and learning tool, the aim of the current project. The adopted operationalised definition was derived from these definitions of systems-thinking as an ability, skill or competence.

An umbrella view of systems-thinking is the ability to think in a systems way which means to think about the whole, the components and links between them (Capra, 1997). These elements of systems-thinking neither embody nor reflect a suggestion or any pedagogical insight of how the biology education should be structured and designed. However, an acceptance of these elements of systems-thinking is in sympathy with a belief of their need and presence in biology education.

If the elements of systems-thinking as ability can be described, then these elements should become an integral part of systems-based education as they seek to enhance and sharpen systems-thinking ability. While it is proposed that this may enhance and sharpen the systems-thinking ability of the learner, there is no intention in this study to measure systems-thinking as a cognitive ability. The proposition is still to be tested further through empirical investigation which is beyond the boundaries of the current research study.

The operational definition of systems-thinking as an educational tool for the present project is suggested:

> *Systems-thinking as an educational (teaching and learning) tool is making the learners aware about the whole (organisational structure of the whole in terms of levels of biological organisation), the parts and the links between them; firstly, by organising the biology education, in such a way which makes the learner aware about the links between components and levels; secondly by providing a framework and an opportunity for the learners to think in terms of levels of biological organisation in context (of the phenomena of transposition).*

In the light this operationalised definition, three specific objectives were formulated which guided the development of the systems-based educational material in the area of transposition:

- To present the ***teaching and learning material*** (the phenomena of transposition) which identifies the levels of biological organisation and explain the connectedness between components and the levels involved.
- To provide an ***explicit framework*** to make learners perceive and visualise the *levels of biological organisation,* the links between levels and their components.
- To provide learners with ***opportunity*** to practice *systems-thinking*

For the development of the systems-based material, these specific objectives were translated into three particular educational elements and practice. The first objective was converted into a *systems-based reading material*, the second one took the shape of systems-*based model as a* diagrammatic representation and, finally, the third one resulted in the formulation of *systems-based activity sheets.*

The development of each of these three systems-based educational elements and the rationale behind is now described.

9.2.2 Rationale for Developing Systems-Based Educational Material

Before presenting the nature and development of systems-based educational material, it is essential to talk about the rationale behind this development. It has been clarified previously that the definition of systems-thinking may differ from person to person and discipline to discipline depending upon the understanding and experience of the person and his/her purpose of using it. Thus, the elements of systems-thinking that an educator wants to use in the development of the systems-based educational material might also be different.

In the present project, the intention was to develop material which would help learners to see the whole, the components and the links between them in the context of the phenomena of transposition. To do this, the major elements of systems-thinking, were derived from the notion of levels of biological organisation.

The importance of the notion of levels of biological organisation in biology education has been highlighted in previous studies. It has been argued that the confusion about levels (Wilensky & Resnick, 1999), lack of ability and willingness to interrelate these levels causes problems in developing a coherent understanding (Verhoeff, 2003; Knipples, 2002). This type of confusion is not restricted to biology.

Verhoeff (2003) and Knipples (2002) point out that many conceptual problems in biology at organismic and cellular levels are associated with lack of interrelating the different levels of biological organisation. A similar kind of problem has been reported in chemistry (Bahar et al., 1999). Miller (2004) also highlights the problem of establishing and linking micro and macro levels in explaining the macroscopic phenomenon with microscopic particles (Meijer et al., 2005). Wilensky and Resnick (1999) also argue that misunderstanding of different phenomena in the world can often be traced back to a confusion of levels. This confusion may start in the class room impacting students' understanding in their formal study and resulting in misconceptions about their experiences of daily life (Wilensky & Resnick, 1999). It is likely that there is a fundamental organisational structure in every domain with different levels in it which needs to be understood for a coherent comprehension of the world.

Different levels can be recognised in a domain depending upon the type of organisation or subject matter one is dealing with. Wilensky and Resnick (1999) have highlighted three different perspectives of level: firstly *'organisation chart view'* in which one thinks of levels in terms of hierarchies of control. Such an approach is normally considered in institutions and other social organisations where one level exercises power or control over an other level; secondly, the *'container view'* which is based on the idea of parts and wholes and that the elements of the lower level are part of higher level element: for example, month is a part of a year; thirdly the *'emergent view'* focuses on the levels that arise from the interaction from the parts at the lower level. Emergent view shares with the container view the idea of parts and wholes; however, in the container view these parts do not interact while in the emergent view the interaction plays a vital role. The emergent view is normally adopted by the new science of complexity which regards biology as a science of highly complex system and investigates how the complex phenomena arise from simple components and interactions. Computer modelling is often recommended for understanding the emergence of the complex phenomena (Wilensky & Resnick, 1999).

In the present research project, the emergent view of level is used, but computer modelling has not been employed. The project used the idea of levels of biological organisation to emphasise the structural organisation of the living systems as a basis of a unified framework for systems-thinking to promote coherent and holistic understanding (Verhoeff, 2003). Although understanding of an organism as a dynamic system is legitimate, this study will not show the dynamic nature of the system. The current project is an attempt to use the levels of biological organisation to develop a coherent, connected and unified understanding in biology education. It is hoped that the notion of levels in addition to providing a structural framework for the understanding of the living systems and a framework for systems-thinking will also pave a path for understanding of the dynamic nature of the organism or a system.

Wilensky and Resnick (1999) reported that the notion of levels can enable people to see systems from multiple perspectives; it can transform learners' views about systems, and can help them to develop better accounts of the interaction and relationships among elements of the system. This is exactly what is the intention behind the development of the systems-based educational material. Apart from making students aware of the levels of biological organisation, it was also intended to make the links between levels and between different components explicit to the learners through the educational material.

By using the concept of levels of biological organisation, the concept of the whole, the parts and links between them, a package of three self-contained teaching and learning units about the phenomena of transposition was developed. Each unit was composed of three elements; firstly, the systems-based reading material; secondly, the systems-based model and thirdly, systems-based activity sheet. The details regarding these three elements are now outlined.

9.2.3 Development of Systems-Based Reading Material

The first specific objective required the development of systems-based reading material. The content of reading material (phenomena of transposition) was taken from the prescribed text book used by the 1st year university students at the University of Strathclyde. The content was selected to identify explicitly different levels of biological organisation.

The content was organised into three units. It was presented in a non-traditional way, different from the textbook and from the way it is taught and presented in classroom and tutorials. To incorporate the element of systems-thinking (concept of levels) into the text, a narrative style was chosen for each unit. Biological content was meshed and grounded with systems-thinking by using a story telling style.

Story telling is said to be one of the most important human inventions, the foundation of the teaching profession (Abrahamson, 1998) and an important learning tool (McDrury & Alterio, 2003). Story is not always fiction. According to Egan (1992), story is shaping the content in a narrative style. Similarly, McDrury and Alterio (2003) define story as a means to translate knowledge into words and images. To him story is a sense-making operation of the mind and he recommends it as an educational practice because even scientists use metaphors and narratives to develop understanding (Ianonne, 2001).

Different purposes and ways of using narrative in teaching and learning have been mentioned in the literature (McDrury & Alterio, 2003; Beck, Mckewon & Worthy, 1995; Ianonne, 2001). Ianonne (2001) has suggested that students can act out events such as cell formation, fission and fusion etc. Beck et al. (1995) put emphasis on working with the text. They argue that the readers' engagement is influenced by the style of the text. They advocate giving voice to the text, which means bringing activity, orality, connectivity and addresivity into the text. By *activity,* they aim to present the situation in a dynamic way; by *orality* to bring the conversational tone of the oral language, by *connectivity* meant drawing connection between events and agents, and *addresivity* meant addressing the reader directly. It has been suggested that story telling can be used to explain how a set of entities can produce a phenomenon (Ogborn, Kress, Martins & McGillicuddy, 2002). Ogborn et al. (2002) argue that the biological components are just as real as the everyday world but they are too small to be seen. Therefore, they suggest scientific explanation in the form of a story with the actors, the entities or things about which the students has to learn (Ogborn et al., 2002).

The use of narrative in education in all subjects has been recommended and a number of educational benefits have also been reported. According to Beck et al. (1995), narrative energizes the text and makes it engaging and then the building of the meaning takes place. Ianonne (2001) comments that narrative material which speaks to the students ignites their imagination which in turn helps to hold thoughts better because imagination unifies the cognitive and aesthetic experience.

Abrahamson (1998, p.1) states *'If one could code knowledge to be passed on and embed it in a story form then it could be made more faithfully memorable than by any other means'* (Quoting Kieran, 1989, p. 456). Similarly McDrury and Alterio (2003) also confirm that narrative stimulates imagination, enhances memory and visualisation skill.

For the present study, it was proposed that a narrative styled presentation would help in information retention and would trigger students' imagination to see the unseen. It was also proposed that the inclusion of the levels of biological organisation explicitly in the reading material would provide a context for their imagination.

For the current study, the biological components were personified and thus were brought into being for students. Students were presented with their conversations just like in Aesop's Fables where animated and inanimate objects speak the human language. The four elements suggested by Beck et al. (1995) were given voice in the text.

For the present study, the biological elements belonging to different levels of biological organisation, such as transposable element, part of an organ (Corn and pea seeds) and organisms (bacterium, *Salmonella typhimurium*) were personified and allowed to speak for themselves. The, transposon (jumping gene) spoke; the corn seed told its story about how it got to know the secret of its speckled seed coat, a wrinkled pea seed provided a tour across the levels of biological organisation to find the causes of its wrinkled pea body. The titles of the units are listed below and the material itself can be found in the appendix (p.289-316).

Unit 1	Nature's Casanova: transposable element
Unit 2	Joseph's Coat: the speckled corn seed
Unit 3	Ugly Sam: the secret of the wrinkled pea seed

9.2.4 Systems-Based Model

The second specific objective led to the development of a systems-based model for each unit. According to Gilbert & Boulter (1998), models can be created for an object, idea, event, systems or process. The educational effectiveness of models has been argued especially in science education. Indeed, it has been stated that it is impossible to teach and learn science without using models (Harrison & Treagust, 2000). The reason is because science teaching and scientific discourse deals with two types of objects: firstly, the things that belong to everyday world and thus are familiar; secondly, unfamiliar things belonging to a different (the scientific) world, such as genes, microbes, ecological niches, atoms, entropy etc which are either microscopic entities or constructions of human mind. Thus, a variety of invisible and intangible entities are dealt with in science education. These entities cannot be encountered in the real tangible world; they inhabit either an unseen or an imagined world; hence, it is important that someone has to make them visible or do the imagining in a way which can assist students in developing understanding. For such purposes models are used to illustrate the imagined world (Amos & Boohan, 2002; Ogborn et al., 2002; Boohan, 2002; Harrison & Treagust, 2000).

In science education, different types of models are used: dynamic models, static models, two dimension and three dimension models, physical models, computer modelling and simulations (virtual laboratories) (Amos & Boohan, 2002; Ogborn et al., 2002; Mayer, 1989; Harrison & Treagust, 2000; Van Driel & Verloop, 2002; Gilbert & Boulter, 1998; Justi & Gilbert, 1999). Model categorisation is possible from different perspectives such as from the perspective of appearance and function. Van Driel and Verloop (2002 quoting Gilbert, 2000) characterise three types of models from the perspective of function, descriptive, explanatory or predictive model. Similarly, keeping in view the role of models in science education, models have been classified such as scientific consensus model, curricular model, teaching models, mental models and expressed models (Gilbert, 2000 in Van Driel & Verloop, 2002; Gilbert & Boulter, 1998; Justi & Gilbert, 1999).

The models which are used by the teachers and the textbooks to present the science knowledge have been termed as *analogical models* by Harrison and Treagust (2000). They have also presented an elaborate typology of analogical models reporting that they can be concrete, abstract or theoretical. These models can have different representational modes such as scale models of object; symbols, equations and graphs; diagrams and maps; and simulation (Gilbert & Boulter, 1998). Mayer (1989) has called text book models, *conceptual models* and defined them:

> *'A conceptual model is defined as words and /or diagrams that are intended to help learners build mental models of the systems being studied; a conceptual model highlights the major objects and actions in a system as well as the causal relations among them'* (Mayer, 1989, p. 43).

This definition reflects that the conceptual model is a combination of a text and pictorial representations of the information. It spells out the major components, highlights the key concepts and also suggests the relationships (Mayer, 1989). Gilbert and Boulter (1998) labelled these as teaching models. For the development of systems-based material, the present project has employed a traditional approach - two dimensional pictorial models. Mayer's (1989) definition has been adopted and used as the conceptual frame-work to develop the systems-based model.

All the above mentioned models have been reported very powerful educational tools assisting teaching and enhancing learning (Amos & Boohan, 2002; Ogborn et el., 2002; Mayer, 1989; Harrison & Treagust, 2000; Van Driel & Verloop, 2002; Gilbert & Boulter, 1998). Models are found useful in a number of ways. They serve as organisational framework to teach the large number of otherwise isolated facts which science has accumulated (Gilbert & Boulter, 1998). Mayer (1989) has supported the use of models by providing empirical evidences for their effect. He has reported firstly that models help learners in improving the conceptual retention, and argues that conceptual models assist the students to direct their attention towards the conceptual objects, locations and actions described in the lesson; secondly, he reports that conceptual models reduce verbatim retention because they help students to organise the information to fit in their mental model and they are less likely to repeat the words. Finally, he has reported that students can answer the questions related to that particular concept presented in the conceptual model even if the information is not directly present in the text or the model.

Apart from being helpful in developing understanding, it has been reported that students can learn to think and work scientifically with models. Moreover, models help students themselves to build and manipulate mental models of abstract and non-observable phenomenon (Harrison & Treagust, 2000). Models have also been argued to bring changes the way students perceive the text and think of it. In this regard, Mayer has commented *'conceptual models ... can lead to changes in the way that students think about the material'* (Mayer, 1989, p. 59). Models have also been described as thinking tools. They have been stated to be an aid to memory, an explanatory tool, and a learning device (Harrison & Treagust, 2000; Gilbert & Boulter, 1998). It has also been reported that the image-like form of the model make them more memorable; their simplification and ready accessibility require the use of less memory capacity and thus reduce the load on both long and short-term memory (Gilbert & Boulter, 1998).

For the current study, the concept of levels of biological organisation has been coupled with a conceptual model and a systems-based model been developed. This model is a diagrammatic representation, showing different levels of biological organisation. The model was presented in the form of a ladder showing different levels, their components and their relationship. The model was named as *the ladder systems model.* Furthermore, a brief textual summary was added to make the point for systems-thinking.

It was proposed that a systems-based model would supplement and reinforce the idea of thinking in levels (systems-thinking). It also would provide a simplified and structured visual representation of the biological organisation and it would also provide students with a cognitive framework for thinking in levels and also for imagining biology concepts. This model intended to explain explicitly the relation between different elements and levels in biological systems. Although in the systems -based reading material the personified biological elements take the readers up and down on these levels. It was proposed that model would make this more explicit. The models can be seen in the appendix (p. 347-349).

9.2.5 Development of Systems-Based Activity Sheets

The third objective was to provide learners with an opportunity to practice systems-thinking. This specific objective was translated into a systems-based activity sheet. It has been documented in the literature that students have a tendency to compartmentalise the knowledge and very rarely students spontaneously integrate the information presented to them (Songer & Linn, 1991 in Kali et al., 2003). The presentation of isolated information (Jocobson & Wilensky, 2006) and students' tendency to compartmentalise the knowledge does not help students to move beyond the retention of facts. To deal with this learning problem, intervention has been recommended in the form of *knowledge integration activities* (Linn et al., 1996 in Kali et al., 2003).

The activity sheets for the present study were also developed to address the issue of developing a coherent understanding. The term, 'activity' hence does not mean to be involved in practical work such as doing, building or constructing something with hands. The purpose of systems-based activity sheet was to involve students in thinking in a systems way which in turn could lead them to develop a coherent understanding about the phenomena of transposition.

Verhoeff (2003) used model building activity where students had to produce a concrete cell model and found this useful for the enhancement of coherent learning of students. Similarly some other studies have involved computer model building and have been reported to be useful for developing and nourishing systems-thinking and coherent understanding (Ossimitz, 2000; Verhoeff, 2003; Richmond, 1993). In the current project, the system-based activity sheets were intended to create opprtunities to work on and think about questions provided in the context of the phenomena of transposition.

It is proposed here that the systems-based activity sheet would provide opportunities for the learners to think in levels: allowing them to integrate the knowledge. Although it is not claimed that these three activity sheets would bring a revolutionary change in students' thinking, it was expected that they would initiate a way of thinking and would provide an opportunity to look at the already known biological knowledge in a systems way. It was also expected that these activities would assist the learner to learn coherently and meaningfully which could lead towards enhancing their performance about the phenomenon of transposition in a test of their understanding.

The activities were paper and pencil based, involving a set of questions which revolved around the levels of biological organisation in the context of transposition. The elements of the activity sheet are following:

System-based guided questions: Questions and search for answers is central to science education. In teaching and learning of science, questions have an important role to play (Amos, 2002; Carr, 2002). Questioning has been reported as one of the most commonly used skills by the teachers. There are a variety of questions and different ways of categorising them such as open or closed; person or subject centred; involving lower or high order thinking skills. A mixture of questions is used in the class room. Most of the time closed questions are used by the teachers to find out how much the students know and can recall. Closed ended question also have the potential to lead students from one idea to another and to help them to make connections between phenomena, ideas and events (Amos, 2002; Yip, 2004).

The types of questions asked by the teachers greatly influence the learners' cognitive structure. Questions focussing on recall reduce the enriching aspect of thinking and encourage learning without understanding. Effective questioning encourages learners to think and promote their understanding. Such questions sometimes called scaffolding questions (Amos, 2002). According to Bruner "*scaffolding questions are used to structure the learners' thinking and take them from their existing ideas to a more complex state of understanding*" (quoted in Amos, 2002, p. 10). It has been suggested that, *"knowledge is not just there in a book, waiting for someone to come along and learn it. Knowledge is produced in response to questions..."* (Postman & Weitgartner in Amos, 2002, p. 15).

The questions included in the present work sheets were not just recall and write. The questions were closed but did not encourage thoughtless answers. Students had to make a deliberate effort to think and link different elements belonging to the levels of biological organisation. They had to visualise and imagine what was being described and extract the answer. Questions were demanding, making students look at things in context and then extract the answer from the information they had and the ideas they had imagined. They had to be active and attentive moving up and down on the levels of biological organisation: 'yo-yoing' (Knipples, 2002). Scaffolding was provided for this movement in the form of guiding questions. Such questions were formulated to encourage students to imagine and think in a systems way (Knipples, 2002; Verhoeff, 2003). Smith (2003) called such questions systems-based questions where relational aspects are emphasised. He reported the importance of systems-based questions associating them with a transforming power, and having a substantial impact on students' understanding and ways of thinking. Yip (2004) also holds similar opinion regarding the impact of questions on students' thinking. It was proposed that the systems-based questions would initiate and stimulate students' system thinking ability and imagination in the context of transposition.

Discussion: Opportunities to engage in discussion were incorporated into the activity. The purpose was to allow students to share and compare their thoughts and to learn from the group situation by speaking and listening.

Drawing: The last element of the activity sheet asked the students to draw a diagram related to the phenomena of transposition in corn seed, and pea seed. It was an opportunity to demonstrate systems-thinking on paper. It was proposed that this would be an opportunity to bring their knowledge of different components from different levels of biological organisation together, in a coherent way. These activity sheets can be found in the appendix (p. 330-337).

9.2.6 Development of Performance Tests

In addition to the development of systems-based educational material, two performance tests were developed to evaluate students' performance by comparing scores. These two tests were regarded as equivalent to each other. The two tests had characteristics similarities: the number of items, the structure, the difficulty level, and the directions for administration, scoring and interpretation (Gay et al., 2006).

The use of standardised tests in research studies is a preferred choice (Gay et al., 2006). In the present project, it was essential to develop tests to compare students' performance before and after the use of systems-based educational material. Great care was taken in designing the tests to avoid ambiguous and confusing sentence structures and inappropriate vocabulary (Gay et al., 2006). Biologists and educationists were given the tests to for comments. Tests were piloted with a small number of biology students.

For any newly developed data collection instrument there is always an issue of reliability and validity. It is important that the test measures what it purports to measure: its validity (Gay et al., 2006; Cohen et al., 2000). The validity of a test has different aspects (Cohen et al., 2000). The important aspect for this study was content validity. Content validity means that the instrument does measure what it purports to measure, fairly and comprehensively (Cohen et al., 2000; Gay et al., 2006). To ensure these concerns about content validity, experts and colleagues in the biology education were consulted (see: Gay et al., 2006; Cohen et al., 2006).

Reliability has also to be established for a newly developed test. Where validity is concerned with the quality of the instrument, reliability has concerns about the consistency and replicability of the results over time, over group of respondents and over instrument. Validity has been regarded as a necessary precondition for reliability: if the test is measuring what it is supposed to be measuring, it should be reliable (Gay et al., 2006; Cohen et al., 2000). However, the conditions under which it is administered may have an impact on the result then even if the test is valid it would not give reliable results. Thompson (in Yu, 2006) argued that reliability is not a property of the test; rather it is attached to the property of the data and thus inconsistency in students' performance across tasks does not invalidate the assessment.

Reliability does not mean that a test administered before the intervention will give the same result as the test administered after the intervention. Students may either improve or forget the information they were given or had learned. Threats to reliability and validity can never be erased completely but they can be reduced. Possible precautionary measures as mentioned above have been taken to make the tests valid and reliable. Copies of the tests can be found in the appendix (p. 361).

9.2.7 Two Survey Questionnaires

Apart from developing the performance test, two surveys were also planned and questionnaires were developed. Both the surveys were of different natures. First, a survey questionnaire was designed to collect information about different experiences of the sampled students about biology teaching and learning. This was called the '*samples' attribute survey'*. This survey covered four aspects: the reasons for finding genetics difficult; their experience of biology teaching at school; their examination preparation preferences; and their preferred ways of studying genetics. For each of these aspects, a number of choices were given in the questionnaire. Students simply had to choose one and or rank their choices.

Secondly, a questionnaire was developed to explore the opinions of the students towards the systems-based teaching and learning materials. The survey questionnaire was called the *"intervention effectiveness survey"*. There are several approaches to explore opinions: three commonly used methods are based on the work of Likert, Osgood (semantic differential) and rating (Gay et al., 2006). For the present project, the Likert approach was adopted (Creswell, 2005; Sutter, 2006).

Likert questions create a powerful data collection tool and are recommended by many researchers for exploring opinions and attitudes towards a target object because they provide a range of responses to a given statement or question (Cohen et al., 2000). However, they have some inherent limitations as well. For instance, there is no check if the respondents are telling the truth; many people avoid the two extremes of the continuum (Cohen et al., 2000). Moreover, there is also a difficulty of analysing the data obtained.

The Likert scales generate an ordinal data (Bell, 2005). With such data, it possible to determine frequencies, modes, carry out cross-tabulation, correlations and chi-square tests; some ranking and non parametric procedures can also be used on ordinal data (Cohen, et al., 2000; Jolliffe, 1986). However, many researchers analyse the data using methods which are parametric by assuming that the ordinal numbers when added together can be treated in as ratio data. In this regard, Reid (2006) has discussed the issues about handling such data and suggests treating the data by methods appropriate for ordinal data. The advice was followed in the current study.

The working memory capacity of the students was measured by using a standardised test called *'digit span backward test'* (Miller, 1956). This, along with the survey and questionnaire are all shown in full in appendix (p.367-371 & 375-378). The completion of the development of all the material (teaching and learning material, performance tests, and surveys) laid the foundation and set the stage for the intervention, the use of the systems-based educational material in a class room situation.

9.3 Implementation Stage

Parallel to the task of developing the educational material, a sample was selected and arrangements were made with the administration at the University of Strathclyde for conducting the research study. The specific objective at this stage was to evaluate the effectiveness of the systems-based teaching and learning material. The sampling and procedural briefing of the intervention are now described.

9.3.1 Sample

The interviews with the biology lecturers (chapter 8) revealed that students often have incoherent and fragmented understandings of many concepts in biology. It was also mentioned that the undergraduates in the latter two years begin to engage and reflect coherent understanding. Therefore first year students were thought to be the group needing assistance to start thinking coherently. The whole biology class of 313 first year biology students (34% males and 66% females) from the University of Strathclyde was selected (table 9.1).

Table 9. 1 Gender and subject distribution of the sample

Group	Status	Gender		Total
		M	F	
A	Biology minor	47	60	107
B	Biology major	17	76	93
C	Pharmacy	38	75	113
Total		**102**	**211**	**313**

There were three groups in the sample: *group A* comprised students studying genetics for the first time in university or were taking it as minor subject; *group B* students were studying biology as their major subject and *group C* were the students doing a degree in pharmacy. All the three groups were treated as one cohort with no intention of comparison. For all the three groups, the same systems-based material, tests and survey questionnaires were administered.

9.3.2 Procedural Briefing

The sampled students were approached during their lab time for 50 minutes on Wednesday, Thursday and Friday for three weeks in March, 2006. The plan for these three weeks is given in the table 9.2.

Table 9.2 Procedures followed for intervention.

Time scale (March, 2006)	Tasks of the intervention	Data sources
1st Week	Pre test 1st unit • Reading material • Activity sheet	Working Memory Capacity Test scores
2nd Week	sample attribute survey questionnaire • 2nd unit Reading material • Activity sheet	Sample attribute survey
3rd week	3rd unit Reading material • Activity sheet • Post test • Intervention effectiveness survey questionnaire	Intervention effectiveness survey Tests scores

For each of the three groups, the procedure used was identical. For example on each three days, reading material was distributed to the students and then they were allowed 20 minutes to read it. After the reading they were given the activity sheets within 20 minutes allotted to complete them. Apart from this reading and worksheet tasks, other data was collected each day *sample attribute survey questionnaire*, *intervention effectiveness survey questionnaire*, and a test for measuring their working memory space was administered. The findings of this phase are presented in the next section: *firstly* the findings of sample attribute survey and *secondly* the findings of intervention effectiveness survey and digit span backward test.

9.4 Outcomes of 'Sample Attribute Survey'

This section presents the findings of the *'sample attribute survey'* (first survey). Both the surveys generated quantitative data mainly of an ordinal nature. Although some do treat ordinal data as an interval scales (Gay et al., 2006), here the data are treated as ordinal and handled using appropriate non-parametric methods (Reid, 2006).

The first survey was designed to explore the teaching and learning experience of the first year university students studying biology at the University of Strathclyde. This survey covered a number of areas: the reasons for finding genetics difficult to understand, student' experience of school classroom teaching, their preferred way of studying genetics, their preferred way of preparing for examinations, their opinion about genetics, and their attitude towards the university internet website as an educational resource.

Inferential statistics were not employed because the aim of this part of the study was to paint a broad picture students' experience of biology teaching and learning. Hence, only descriptive statistics are used. The data are presented as percentages to the nearest whole number for clarity although any analysis is based on the actual frequencies. In the tables, interesting patterns of numbers are shaded in colour for clarity. Each question is now discussed in turn.

(1) Reasons for finding genetics difficult to learn

	Genetics is difficult to learn (N = 261)	**%**
A	I find genetics difficult to understand.	32
B	There is too much information involved in genetics.	48
C	The large number of genetic terms make it difficult	52
D	There are too many concepts to grasp.	41
E	It involves chemistry and this makes it difficult.	15
F	Genetics is not related to observable phenomena	12
G	I do not have enough time because of workload of other subjects.	28
H	The way I was taught at school did not suit me.	8
I	Genetics deals with the most complex part of living beings.	27
J	Some concepts involve mathematics and this makes it difficult.	11
K	I find it difficult to visualise things at the microscopic level.	39
L	To understand genetics requires me to hold too much information at one time	32

Table 9.3 Data: question 1

It is interesting to note that the students do not indicate that either mathematics or chemistry is causing the problem. This contradicts expectations in literature. Genetics terminology has appeared at the top the list in making genetics hard to learn. This is consistent with what has been expressed by the biology lecturers in section 8.7.1 and reported in literature by many (section 5.3). Students also do not blame their previous school experience. However, students do identify problems relating to the amount of information (parts B, C, D and, especially, L). This could be a reflection of working memory space overload when they are trying to handle too much information at the same time. This is consistent with findings of Chu (2007) where measured working memory capacity was found to be highly correlated with performance success in genetics examinations.

The other key finding is the identification of complexity of biological systems as a source of difficulty. Visualisation of levels of the microscopic details seems to be a problem which is consistent with the reports of many researchers (Knipples, 2002; Verhoeff, 2003). Many reported the importance of using the models to make explicit what is not concrete or perhaps is too small for the naked eye (Amos & Boohan, 2002; Ogborn et al., 2002; Harrison & Treagust, 2000).

(2) The most and least used teaching strategies in the school class room

	How students were taught (N = 261)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
		Most						*Least*
A	Delivery of information in a lecture	31	15	11	15	10	7	11
B	Working in groups and discussion	4	9	15	16	15	18	24
C	Use of visual material during teaching	22	24	12	16	13	7	6
D	Teachers' reliance on text books	29	12	11	10	12	13	13
E	Encouragement to work on their own	2	8	8	11	16	26	29
F	Arrangement of discussion with students as a class	8	16	19	14	18	16	9
G	Use of past exam papers to guide the work	3	16	24	19	15	14	8

Table 9.4 Data: question 2

The outcome uncovered by this statement is not surprising. It was found that most of the students had experienced a lecture delivery approach with heavy reliance on a text-book. Much visual material was involved during the teaching, and examination papers were used to guide the work. Group discussion and collaborative work seems not to be common in the classroom. Students' responses reflect the typical picture of a school situation which is consistent with the opinion of biology lecturers presented in section 8.7.2.

(3) Students' preferences to learn to prepare for an exam

	Preferences in preparing for an exam (N = 261)	**%** *overall*	**1st**	**2nd**	**3rd**	**4th**
A	I like working with others	42	12	11	11	8
B	I like practical activities	35	6	8	10	10
C	I like doing things for myself	59	23	15	12	8
D	I prefer the lecturer to provide everything	49	12	13	13	11
E	I rely on memorisation	59	17	20	11	12
F	I rely on understanding	65	19	18	16	12
G	I enjoy intellectual challenge	20	3	3	4	10
H	I avoid difficult material	13	1	2	4	5
I	I like practical implications to be emphasised	25	3	4	8	10
J	Theoretical material is important to me	27	4	4	8	10

Table 9.5 Data: question 3

Students' preferences in preparing for examinations indicate an interesting dichotomy between memorisation and understanding along with a strong wish to do things on their own. This suggests that they need to have time to think things through. Looking at the memorisation and understanding dichotomy, it is found that students who picked the one usually did *not* pick the other. This shows that there is a difference in the class: some prefer memorisation, others prefer understanding. An interesting discussion around memorisation and understanding can be initiated but it is not the intention of the present project. Apart from this, the power and importance of lecture is also evident from the students' responses. This is consistent with the opinion of biology lecturers where they felt that students spoon-fed in school and face difficulty in taking the responsibility for their own learning at university level (section 8.7.4)

(4) Students' preferences in studying genetics

Statements about preferences in studying genetics (N= 261)					
		%			**%**
A	Reading lecture notes	72	E	Using website	12
B	Reading the text book	37	F	Trying previous exam papers	65
C	Making revision notes	57	G	Using quizzes on spider	22
D	Talking to others	19	H	Other …….	19

Table 9.6 Data: question 4

Responses provided information about students' preferences for studying genetics. Three items stand out. It is clear that lecture notes are critical for students. They like to make revision notes and also rely on examination papers. Indeed, the examination papers may be providing information about what is required of them. The text-book is favoured by the learners as a preferred source of information to using the web or talking to others.

(5) Students' views about genetics' knowledge (N = 261)

I enjoy studying genetics	8	19	33	20	15	5	Studying genetics is boring
Genetics is difficult to understand	13	27	32	19	7	1	Genetics is easy to understand
Genetics knowledge is only facts	1	10	24	30	26	10	Genetics knowledge involves concepts
Genetics knowledge is microscopic	2	9	22	24	22	21	Genetics knowledge is **not** only microscopic
Genetics knowledge is abstract	2	12	36	33	15	3	Genetics knowledge is concrete
Genetics knowledge is isolated information	2	3	10	21	40	24	Genetics involves linking information
Scientists tend to disagree with one another	8	15	27	33	16	1	Scientists tend to agree with one another
Genetics knowledge is static	1	4	17	32	30	17	Genetics knowledge is dynamic
Genetics knowledge is relevant to our daily life	23	36	16	13	7	6	Genetics knowledge is irrelevant for daily life
It is important to make the public aware of new research findings in genetics	34	34	21	7	3	1	It is **not** important to make public aware of new research findings in genetics
Genetics knowledge in our text books is absolutely true	0	16	37	30	12	5	Genetics knowledge in our textbooks is **not** absolutely true
Scientific research finding are influenced by the scientists' biases	2	17	45	23	11	23	Scientific research finding are **not** influenced by the scientists' biases
The objects of study, living things, in genetics appear to be complex systems.	27	37	27	7	2	0	The objects of study, living things, in genetics are not complex systems
I can see different branches of biology connected.	30	41	20	5	4	0	I cannot see different branches of biology connected.

Table 9.7 Data: question 5

This question attempted to discover how students value genetics as a discipline in the broader context of biology, and the way science conducts its inquiry. Some broad observations can be made. They see the importance and relevance of genetics to life and that people should be aware of the way genetics is developing and its implications. They are aware that genetics knowledge is moving fast with massive social implications. They are also strongly aware that genetics is difficult and they are seeing genetics as a complicated area dealing with complex system. They are also clearly conscious that genetics involves linking information.

(6) Students' response towards the use website as an educational source

The department had expended much time and energy developing a website but they had the impression that it is not being used as much as they would like (table 9.8). Therefore, this question was incorporated as an opportunity to explore what was happening and the outcomes show that it is not being used frequently as a source of information to study genetics.

	Frequency of usage	%
A	Every day	2
B	Once a week	20
C	Never	13
D	Near the examination	64

Table 9.8 Data: questions 6

(7) Reasons students suggest for avoiding the use of website

	Reasons	%		Reasons	%
A	There are too many links	39	**F**	I find it hard to follow the connections	22
B	It is too time consuming	43	**G**	I do not have convenient access to the internet	12
C	I rely on my teacher	24	**H**	I prefer reading the text book	61
D	There is too much information on the screen	42	**I**	It is not well structured	19
E	It is difficult to extract relevant information	73	**J**	When I move I forget the previous screen	31

Table 9.9 Data: questions 7

The students' responses to this statement indicate clearly that a large proportion of students prefer using the text-book and it is consistent with the outcome of statement 2 where the teacher reliance on a book was noted. The possible interpretation could be that perhaps it is an issue of cognitive style of the students. Chen and Stroup (1993) have reported that field independent students derived more learning gains than the field dependent students from computer simulations.

They find it difficult to extract relevant information (E). It also shows an information overload situation (A, D). There is not much evidence available from the published studies relating the roles of working memory space and extent of field dependency when learners use web based materials.

9.5 Summary

The sample attribute survey shows that complexity of living beings, problems of visualising the microscopic details, too much information, too many concepts and too much terminology makes genetics difficult to understand. Secondly, the students' response to the teaching strategies is much as expected: group work is least used and independent work also seems least encouraged; textbook dependence and didactic teaching seem to dominate.

Thirdly, almost half of the students expected or hoped that their teachers would provide everything. There is some interest in group work and a desire to work on their own. Some rely on understanding and some on memorisation. Fourthly, their preferred strategy for studying genetics are reading lecture notes, examination papers and making revision notes. The text-book is preferred over all other sources available to them. They see genetics as a difficult area to understand; they are aware of the dynamic nature of genetics knowledge, its relevance to life and the public awareness of this knowledge. They are certainly aware that genetics deals with complex systems which involve thinking and connecting information. Finally, web sources are not frequently used. There seems to students to be too much information and a difficulty of extracting relevant information.

The elements reported in making genetics difficult to understand provide an indication how to deal with the genetics knowledge (the problem of complexity; problem of visualisation; and overload of working memory space). Any educational material dealing with genetics with a systems approach should deal with the nature of systems, their hierarchical nature, extent of connections, rather than reducing it to isolated components. The problems related to visualisation of microscopic detail, and information overload must also be considered. A systems-based text should develop links explicitly by introducing the levels of biological organisation and this may be aided by stimulating the imagination.

For the current study, systems-based-educational material was developed and used with the students. Students' opinion about this material is presented now.

9.6 Outcomes of 'Intervention Effectiveness Survey'

The second survey was conducted after the intervention and aimed to find out the effectiveness of the systems-based educational material from the students' perspective. Twenty statements in the survey were divided into 5 broad categories. These categories reflect students' attitude towards:

(1) The systems-based teaching and learning material
(2) Their own thinking
(3) Their own understanding of biological systems
(4) Their understanding about the phenomena of transposition
(5) Teaching regarding systems-based approach

It was possible to compare the responses of three groups of biology students (section 9.3.1) involved in the intervention. An analysis using chi-square revealed that the three groups were responding in a similar way towards the systems-based educational material (data shown in appendix). Therefore, it was decided to treat the sample as a uniform group.

In considering students' responses, the responses to each statement are considered separately under the headings of the five broad groups. This is followed by a discussion of the category.

(1) Attitude towards the systems-based teaching and learning material

The major purpose of these questions was to find out how students found the new material. These are their expressed views and need to be interpreted with caution.

(a) *I liked the presentation of the material about transposition, pea seed and corn seed in a different way from my textbook.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
10	40	26	16	8

Table 9.10 Data: question (1 a)

Although only 10% students show very positive view, yet 50% overall are showing a positive response, the distribution being heavily skewed to the left. Less than one quarter respondents hold negative views. The material was well perceived by the learners.

(b) *The questions in the worksheets were helpful to make me think.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
7	46	28	16	3

Table 9.11 Data: question (1 b)

More than 50% of students opted for the positive end of the spectrum, again with only a few opting for the very positive response. Nevertheless, the general impression and feeling is that their thinking was positively influenced. This suggests that questions engaged students in thinking which was the intention behind the activity sheet.

(c) *The activities helped me to visualise levels in a system.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
5	50	33	11	2

Table 9.12 Data: question (1 c)

A very similar pattern of response is observed towards this statement with a very high proportion of positive responses. It seems that the materials have been found helpful in grasping the concept of levels and then seeing them in their imaginations. This grasp of the concept of levels and ability to visualise levels can greatly assist in thinking and developing understanding.

(d) *The activities in the worksheets helped me to understand the links between different levels of biological organisation.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
5	54	30	8	3

Table 9.13 Data: question (1 d)

The responses to this statement are largely positive. The interpretation of this finding is that presenting the links explicitly and then posing questions involving levels has been useful in developing understanding. This was a specific aim of the materials.

(e) *The group work was useful to develop understanding.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
6	39	37	15	4

Table 9.14 Data: question (1 e)

While there are more respondents who are positive than negative, the collective proportion of responses on the positive end of the spectrum is smallest among all the component statements in this category. This suggests that group work was not seen as unequivocally helpful in terms of developing understanding. It was observed during the exercise that all students were not always fully involved in the group work, some tending to work individually. The experience of group work was perhaps unfamiliar. This observation is consistent with what this sample expressed about their school experience presented in section 9.4 statement 2

(f) *The activities did add to my understanding of transposition.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
6	45	29	15	4

Table 9.15 Data: question (1 f)

Again half of the responses fall towards the positive end of the spectrum, indicating that students regarded the activities' contribution towards developing understanding of the phenomenon of transposition.

Conclusion

To conclude, the descriptive representation of the findings is encouraging while not offering overwhelming support to the effectiveness of the materials. It can be deduced that the material was liked by a high proportion of the students; the activities were found contributing in stimulating thinking, encouraging visualisation, making links clear, and developing understanding of the phenomena of transposition. The outcomes have provided evidence that systems-based educational material has the potential to assist students in developing their understanding.

(2) Attitude towards their own thinking

It was proposed that systems-based teaching and learning material would influence students' thinking. The findings in this regard are presented below.

(a) *I realise that thinking in levels can make genetics easy to understand.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
9	50	33	7	2

Table 9.16 Data: question (2 a)

It has been found that, although a very strong positive attitude is only reported by a small fraction, nonetheless over half of the students clearly agreed that thinking in levels or systems-thinking can make it easy to comprehend the complexities of genetic. This suggests that it is appropriate for a systems approach to be incorporated into the teaching and learning.

(b) *I can apply this sort of thinking with the other topics in genetics.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
7	44	37	10	2

Table 9.17 Data: question (2 b)

It is also encouraging that around half of the respondents are on the positive end of the continuum, believing that they can apply this sort of thinking to other topics in genetics. Nevertheless, a quite big proportion of the students (37%) are neutral, suggesting a measure of uncertainty. Nevertheless, this finding signals a positive indicator for the effectiveness of a systems approach and students see the systems approach as being transferable.

(c) *I have developed a way of thinking in levels after these activities in laboratory times.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
3	28	51	16	2

Table 9.18 Data: question (2 c)

This statement shows a very different pattern of responses, with a big proportion of the sample remaining neutral in responding to this statement. Nonetheless, 31% were positive with only 18% negative. The probable explanation is that to develop or adopt a new way of thinking demands a longer time. They had little opportunity to think this way as a part of their normal teaching and learning in the biology class or it could be that they felt they already had this way of thinking.

(d) *As a result of these activities, I have started thinking in terms of levels while studying biology.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
3	29	43	22	3

Table 9.19 Data: question (2 d)

In response to this statement, the distribution of the responses is very balanced with a high proportion being neutral. The possible explanation for such response could be that either this statement was too early to be asked or students already had this way of thinking.

Conclusion

This category of statements about students' attitude towards their own thinking shows an encouraging picture. Many students (50%) seem to appreciate that this approach can assist their learning in genetics and can be applied more widely. However, their opinion about having developed and started thinking in systems way is not very positive. It is difficult to interpret this situation from the data available. The approach almost certainly needs much more development if this kind of thinking is to be widely applied and to become a way of thinking in biology education. Thinking patterns do not change spontaneously; a considerable and substantial amount of practice and teaching is needed to provide where students are exposed repeatedly and consistently to systems-based activities. Rihmond (1993, 1994) saw formal education as the best potential to bring maximum change and Smith (2003) argued the consistent, repeated and intentional use of systems-thinking to make it a habit of mind.

(3) Attitude towards their own understanding of biological system

The response to this group of statements throws light on students' understanding about biology in general with the reference to thinking in levels.

(a) *I can <u>now see</u> living systems <u>are arranged in levels</u>*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
11	62	23	3	2

Table 9.20 Data: question (3 a)

The positive end of the spectrum has been opted by 73% of respondents. This suggests that the new material has been found effective in presenting the levels in a system.

(b) *I can <u>now</u> see the <u>link between</u> the molecular level and organism level*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
7	58	28	7	0

Table 9.21 Data: question (3 b)

For this statement as well, students' responses are inclined towards the positive end. This can be interpreted in the light of the previous statement. If one is aware of the existence of the levels in a system then it is easy to see and link these levels with one another. It is evidence that systems-based material has been found helpful in making students aware of the links between micro and macro levels in a system.

(c) *The idea of levels in genetics was evident to me <u>for the first time</u> when I completed these exercises*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
3	24	32	33	8

Table 9.22 Data: question (3 c)

Quite a high proportion says that they were not unaware about the concept of the levels. However, this might simply reflect the common terminology of biology and it is possible that the concept of level has been confused with the common concepts used in biology.

Conclusion

The general impression is that the new material was useful in helping students to understand the multi-level nature of biological systems and the links between the levels. However, responses reflect that the idea of thinking in levels was not new for some of the students. Perhaps there is a need to explore their understanding further by interviewing but time and access to students did not permit it for this study.

(4) Attitude towards their understanding about the transposition

This group of statements relates to the three units presented to them: concept of jumping gene, corn seed and pea seed.

(a) *I <u>understand</u> the subtopic "jumping genes" <u>better now</u>.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
14	54	26	5	2

Table 9.23 Data: question (4 a)

This is the highest percentage of strong agreement in the favour of any component statements in the whole survey. Therefore, it is a strong and substantial indication that students considered that they gained benefit in terms of their understanding of the phenomena of jumping genes. Thus, they feel their understanding was better than what they had before the use of teaching and learning package. It is not appropriate to attribute the enhancement of understanding solely to systems-based material. There is a possibility that mere revisiting of the topic enhanced their understanding.

(b) *I can <u>easily relate</u> the phenomena at molecular level to the organism level in the case of the wrinkled pea seed.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
7	40	39	14	0

Table 9.24 Data: question (4 b)

The vast majority show either agreement or are neutral in responding to this statement. Perhaps the word 'easily' in the question is the problem. Overall, the general picture goes in the favour of positive response indicating that unit: Ugly Sam, the secret of wrinkled pea seed, has been effective in relating levels.

(c) *I <u>do understand</u> the phenomena of transposition in the corn seed <u>better than before</u>.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
5	52	28	12	3

Table 9.25 Data: question (4 c)

The response pattern indicates that the students consider that the teaching material has had an impact on their understanding about the transposition in case of corn seed. However, similar interpretation as in the previous statement implies here.

(d) *I still need to <u>have additional support to understand</u> transposition and the speckled corn seed*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
8	37	34	20	2

Table 9.26 Data: question (4 d)

The response towards this statement needs to be considered in the light of the previous question. While they indicate that they understand better than before, they are clearly still wanting more support.

Conclusion

The students' own opinions about their understanding seem to appear positive. However, unpicking the impact of systems-based material and mere revisiting of the concept on students' understanding is difficult from the data available. Careful experimental measurement about the effectiveness of the material in terms of students understanding is needed and recommended.

(5) Attitude towards teaching regarding systems-based approach

This set of statements reflects students' opinions about the biology teaching practice in three different time frames if they were exposed to systems-based teaching.

(a) *I was never taught in the past to think in terms of levels*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
6	36	22	28	8

Table 9.27 Data: question (5 a)

The proportions agreeing does not differ much than those disagreeing. Clearly, roughly equal proportions have been taught this way in the past as those who have not. Because the lecturers have indicated that thinking in terms of levels is not part of the teaching practice, it is highly likely that students have confused the concept of level with the general concepts of biology using the same terms such as organ level or cellular level.

(b) *I would appreciate to have such level based activities for other difficult subtopics in genetics.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
8	46	28	14	4

Table 9.28 Data: question (5 b)

The responses in the favour of this statement are more than 50%, with only 22% disagreeing. This does suggest that the approach has met with some favour and indicates the overall usefulness of the systems-based material used with them.

(c) *My teacher explained the phenomenon of transposition and corn seed in his lecture with reference to different levels.*

Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
1	28	45	24	1

Table 9.29 Data: question (5 c)

The distribution of responses is equal on both sides of the spectrum. It is difficult to interpret the statement.

Conclusion

It has been noted clearly that students would prefer to have systems-based material in future for other topics as well but the picture about their past experience of teaching with reference to the concept of levels is not clear. Similarly, their opinion about the way of their own biology teacher is difficult to interpret.

9.7 Difficulties of Drawing Diagrams

The second question of the survey was related to the questions in the activity sheet where the students had to draw a diagram to illustrate their understanding. Most of the students did not draw diagrams in the activity sheet and in the test question as well. Therefore, students were asked about the difficulties in drawing the diagram. Table 9.30 shows the reasons they suggested for finding it difficult to draw diagrams.

	Reasons	%		Reasons	%
A	Hard to visualise microscopic information	29	**D**	Difficult to think in terms of level	7
B	Hard to link different levels	10	**E**	Hard to think a way to pull all the components and levels together	39
C	Hard to pull all the components and levels together	24	**F**	Too much information to recall at the same time for drawing	33

Table 9.30 Visualisation Problems

Their difficulties of drawing the diagram revealed through their responses perhaps indicated their problem of too much information and also a difficulty associated with microscopic nature of their phenomenon. They also found it hard to think a way to present all the information from different levels.

9.8 Summary

Students' opinion revealed through the survey provides indirect evidence about the effectiveness of the systems-based educational material. They said they found it stimulating their thinking, visualisations, and also in making and understanding links between different levels of biological organisation. Students have realised that systems way of teaching can make genetics learning easier. There is also a realisation that that they can apply it to the other difficult topic in genetics. Their attitude towards their own thinking, after having experience with systems-based educational material is not clearly positive and interpretation of the response pattern is difficult from the available data. Nevertheless, majority of them felt that it improved their understanding of the phenomenon. However, it is difficult to attribute the improvement of their understanding solely to the systems-based material. For such attribution further experimental investigation is needed. More than 50% of the students expressed their opinion to have such systems-based activities for the other difficult topics in genetics.

9.9 Outcome of 'Digit Span Backward Test'

Students' working memory space was also measured but the sample size was small. However, in spite of the small sample size (113), the picture which emerged reveals the normal distribution of the population in terms of their working memory space with mean of 6 and standard deviation of 1.2. This is exactly what would be expected from a digit span backward test as this test gives approximately a mean value less than seven for an adult population. T-test (as independent samples) showed no difference between men and women (t =0.003) as the mean and standard deviation of working memory space for both the genders is equal.

9.10 Outcome of the 'Approach Finding Survey'

In this particular inquiry, students were presented with a number of biological elements belonging to different levels of biological organisation and were asked to arrange them in any logical order. There were two approaches e.g. top-down approach (TODA), if they start with looking at the elements belonging to the upper levels of biological organisation, and bottom-up approach (BUPA) if they pick the elements belonging to the lower levels of biological organisation as their first choice for their logical arrangement. It was possible to consider any difference between male and females in their approach (BUPA & TODA) using 2x2 contingency chi-square test (table 9.31). This shows that women tend to have BUPA compared to the men. This may reflect the tendency for women to pay more attention to abstract details and for men to concrete objects.

Table 9.31 Students approach towards part whole structure

Gender	TODA	BUPA	χ^2=7.5	P<0.01	df=1
Males	15	15			
Females	21	50			

Looking at the approach taken by the students, a t-test showed that there is no difference in working memory capacity between those who adopted a TODA and those who adopted BUPA (t =1.14).

The working memory capacity measurement were correlated with the students test score giving Pearson r = 0.16 (ns). This indicates that test did not favour those with higher working memory space because the question in the test perhaps did not put the cognitive load on students.

9.11 Summary of Second Phase

Overall, at the end of the second phase it is concluded that students found genetics difficult because of the complexity involved, problems of visualising the microscopic details, and too much terminology and information. Students' experience of school classroom teaching was found consistent with what lecturers believed and the literature revealed. At university level, textbooks and lecture notes were found as preferred choices over the other information sources by the students. The intervention effectiveness survey overall showed a positive attitude towards the systems-based educational material for making learning of genetics easier. Findings of the digit span test revealed what was expected with no gender difference in the working memory capacity. A gender difference has been found where women seem to be more mindful towards abstract details and men towards concrete objects. No correlation was found between students' approach (BUPA & TODA) and their working memory space. Similarly, their working memory space and their performance on the test score correlated but not significantly and this might suggest that the nature of the questions asked was appropriate (they did not make excessive demands on working memory).

In the light of the difficulties in this phase, the next phase of the study was planned so that further insights might be gained about the use of such teaching materials with students.

CHAPTER TEN

Further Insights into Systems-thinking in Biology

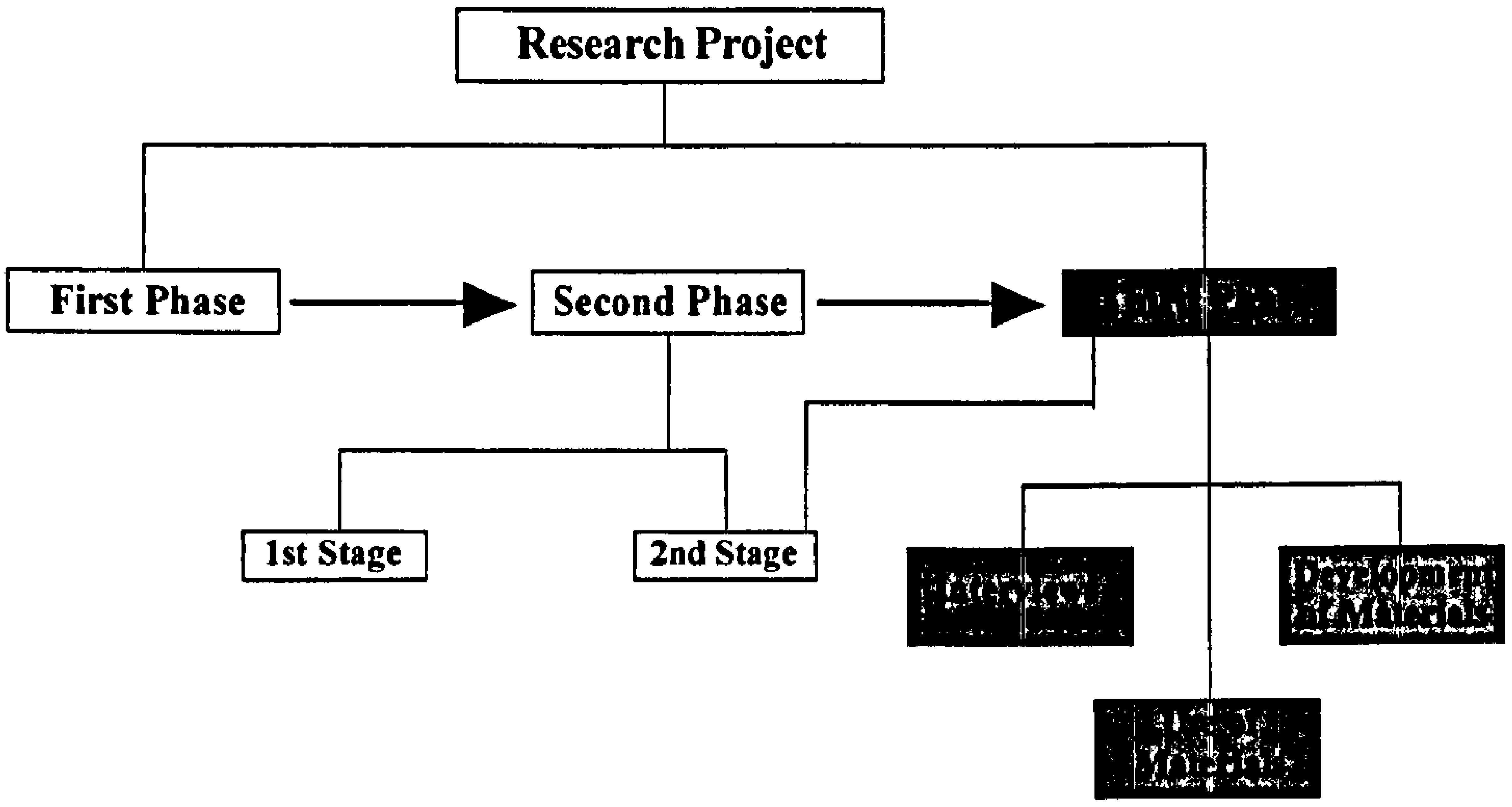
(Third Phase)

This chapter describes the third phase of the project. It describes the nature, methodology and the procedures adopted to accomplish three different research tasks and presents the outcomes from the first task.

10.1 Nature of the Third Phase

The third phase extends and elaborates the previous two phases and took place from August to December, 2006. The opportunity arose to work with a team of researchers in the Netherlands who were involved in developing systems-based teaching approaches in biology education. They were interviewed about the use of systems-thinking in biology education. Taking into account the experiences in the second phase in using systems-based teaching materials as well as the experiences in the Netherlands, these materials were adapted and re-used with students in Pakistan.

Figure 10.1 Activity diagram for third phase of the project.



10.2 The First Task: Interviews

A group of biology educationists researching in this area in the Netherlands was approached and their opinion explored about the use of systems-thinking in shaping biology education. The reason this group was chosen was that their research work in biology education involved the notion of systems-thinking. They were recognised as experts in the field as an information-rich source who could provide the very useful information to achieve the intended objectives of the study.

Six biology educationists were involved. It was a heterogeneous group in terms of their teaching experience and level of teaching (table 10.1).

Table 10.1 Attributes of the sample

Respondent	Gender	Status	Teaching Experience	Level of teaching
1	Male	PhD(student)	34 years	Secondary
2	Male	Professor	35 years	University
3	Male	Professor	34 years	University
4	Male	Post Doc	Students Assistant	---
5	Female	Post Doc	BEd, no experience	---
6	Male	Professor	6 years	College and University

Semi structured face-to-face interviews were conducted. The interview schedule had four sections dealing with four issues: *nature of systems-thinking, biology education and systems-thinking, systems theory and biology education*, and *impact of systems-thinking*. The interviewees requested a copy of the questions to be sent to all before conducting the interview. Interviews were digitally recorded and then were transcribed for analysis.

10.3 Second Task: Development of Materials

The second task was connected to the extension and repetition of the intervention stage of second phase. In the light of the experiences in the second phase and the experiences gained in the Netherlands, the systems-based teaching material was refined.

Two tasks were carried out simultaneously. While the biology educationists were interviewed, the material was also refined and developed. The suggestions from biology educationists were at hand for the refinement of the material and recommendations were taken into account to improve the systems-based educational material. In the process of refinement, two types of alterations were made in the educational material: *firstly* some conceptual improvements were brought into the material to make it more explicitly systems-based and, *secondly*, minor alterations were made to make it suitable for the students in Pakistan. All the material prepared can be found in the appendix. In the following paragraphs, the alterations made to all the elements of the teaching and learning package are outlined.

Systems-based reading material structured in a narrative style was supported by the biology educationists. Only a few changes were made. *Firstly*, a brief introduction was added before the actual reading material to prepare students mentally what to expect. The importance of levels of biological organisation for understanding biology was mentioned in this introduction. S*econdly* to guide students' thinking, to make the reading meaningful and to facilitate the process of understanding, the text was given two voices (voice of the personified element and that of the instructor). Students' were made aware when the personified elements were speaking. For this purpose small iconic figures were added accompanying the text; *thirdly*, diagrams were slightly changed to make them simpler and clearer. The idea of levels and the links between levels and components were made more explicit in the text.

The systems-*based model* was originally presented in the form of a ladder and was called *ladder systems model*. Although this reflected the hierarchical nature of the levels of biological organisation, it did not show the open and the nested nature of the biological system. Therefore, the ladder systems model was replaced with a *nested systems model.* The nested nature was presented by using circles within the circles along with arrows. Similarly, to show and emphasise the open nature of system, broken lines were used, along with the directing arrows. In the light of the suggestions, the number of levels was reduced by packing some of the previously mentioned levels in some broader categories. Thus, the levels of biological organisation included organism, organ, tissue, cellular, sub cellular levels. A copy of the refined systems-based model can be found in the appendix (350-351).

The *systems-based work sheet* for each unit, previously called an activity sheet, was now called *'work sheet'* to avoid the potentially misleading connection with physical activity. In the altered form, there were two parts in the work sheet; firstly, a *model-based sheet* and secondly the *text based work sheet.* A copy of both the sheets can be found in the appendix (p.338-345). The purpose behind both work sheets was to emphasise a thinking pattern (systems-thinking) and also to reinforce this thinking pattern by providing multiple opportunities to think and work.

Some other alterations were made in the previously developed *text-based work sheet.* For example, the discussion part in the previous sheet and all the questions which were dealing with the reproduction of the factual information were replaced by an *oral revision question*s sheet. The oral revision question sheet was used by the teacher, with the whole class as a group. All the questions in the work sheet were designed to make students think about links rather than just recall factual information.

The refined questions required a deliberate effort to imagine and think before giving an answer. Some of the questions were broader in the sense that they took the students from abstract theoretical understanding to the real world as imagined scenarios were presented to them. The text-based work sheet was designed to stimulate their imagination so that they would be forced to imagine and think in terms of levels and their connections. The questions involving drawing were kept to provide students another opportunity to think and link by putting their understanding of the topic in the form of a diagram. The *model-based work sheet* differed from the text-based work sheet because it had a visual representation of the whole phenomenon (levels of biological organisation and components of levels) along with the questions. Questions related to the model were closed questions (p. 345).

It was proposed that the *visual presentation as a scaffolding* would enable the students to think in levels by actually looking at the model. The proposal behind the text-based work sheet was that it would provide *guiding questions as a scaffolding* to think in levels using their imagination. It was proposed that the questions would facilitate systems-thinking and also they would initiate thinking in levels (systems-thinking). To conclude, both the work sheets provided scaffolding for the learners to think in levels but the nature of scaffolds were different; one offers the visual presentation while the other forces the students to think in levels through guided questions.

The *Performance test* also went through certain changes: The revised content of these questions covered only the first two units. Test included three types of questions: closed questions, partly open ended and fully open ended.

Other material was also developed and the data collection instruments planned. It was known that the topic (the phenomenon of transposition) was not a part of the curriculum in the two colleges in Pakistan. It was decided that the researcher herself, having teaching experience, would teach the systems-based material to the biology students in Pakistan.

In the previous phase of the study, the notion of systems-thinking was embedded in the learning package rather than having this concept explicitly explained. Students had to work it out for themselves. However, this time it was planned to introduce the notion of systems-thinking formally to the students. For this purpose, an *introductory lecture* was planned to be delivered before the teaching of the material about transposition. The lecture covered the concept of system, open system, idea of levels of biological organisation, concept of connectedness, and concept of boundary and also the importance of thinking in levels.

The lecture was sandwiched between two exercises: an *anchor exercise* and a *supporting exercise*. The *anchor exercise* was a warm up exercise. Students were given a list of elements and they had to arrange the given elements in any logical order. This brief exercise provided an anchor for introducing the notion of systems-thinking especially hierarchies of levels. This exercise was used in addition as a data collection instrument and was called the *'approach finding survey'*. The lecture was followed by a simple exercise called a *'supporting exercise'*. This was in the form of a brief text which was read and converted into a diagram showing as many links as possible. The purpose of this exercise was to provide students with an opportunity to look for the links.

To explore students' opinions about the material, the previously developed survey, *'intervention effectiveness survey'*, with minor changes was used; a semi-structured interview schedule was also developed to gather students' views about their learning. Similarly, the previously used ' *digital span backwards test* 'was used to measure students working memory space.

10.4 Third Task: Implementation

The third task was the use of the refined systems-based material. Two colleges in Abbottabad, Pakistan, were contacted and arrangements were made. The reason for carrying this research activity in Pakistan was difficulties which occurred during the phase two. Phase two had compromised the quality of its design and the conclusion which could be drawn. The refinement proposed by the interviews of colleagues in the Netherlands had greatly improved the quality of intervention. The colleges in Pakistan were enthusiastic about becoming involved in the research. It is emphasised that there was no intention of making comparisons between the samples from Scotland and Pakistan. Each was an exploratory case study.

Government Girls Degree College No. 1 and No. 2, located in Abbottabad, (North Pakistan) were selected because the researcher was known to the colleges and to their staff members. Students included in the sample were in first year BSc biology major, equivalent to the first year university students in UK. As girls are educated separately therefore it was not possible to gain access to boys. Details of the sample are shown in table 10.2.

Table 10.2 Attributes of the sample

College	Sample size	Age range	Time of implementation
College No 1	40	18-20	6th-9th December, 2006
College No 2	20	18-20	11th-14th December, 2006

The task was spread over four days in the two colleges (table 10.3). On the first day, the students carried out the anchor exercise and received a formal lecture about some elements of systems-thinking. After the lecture, students were presented with a systems-based model showing explicitly some of the concepts. This aimed to reinforce the concept. Then the students were engaged in the *supporting exercise.*

On the second and third days, units one and two were used in the classroom (table 10.3). Each day, students were taught the content by the researcher; systems-*based reading material* was given to them along with the *systems-based model*; *oral revision* was conducted with the whole class with the help of the researcher and finally the *work sheet*, was handed over to the student to provide them an opportunity to practice systems-thinking in the context of the phenomenon of transposition.

Table 10.3 The procedural briefing of the intervention for two colleges

Day: Title of the day	Teaching and Learning Activities Data collection	Time
1st day: Introduction to systems-thinking	Working memory space (WMS) measurement. Anchor exercise. Lecture on systems-thinking. Supporting exercise.	1:30 minute
2nd day: 1st unit implemented	Teaching session. Reading material. Oral revision. Activity sheet.	2:15 minute
3rd day: 2nd unit implemented	Teaching session. Reading material. Oral revision. Activity sheet.	2:15 minute
4th day: Different assessments	Assessment test. Attitude survey. Group Interview.	2:30 minute

On the fourth day, students were assessed. A survey was used to explore students' opinions about different elements of the teaching and learning materials. A group interview (see appendix p.374) was conducted to gain insights into their whole experience with systems-based teaching and learning. For group interview, students were divided into groups of five and were given a question sheet to present a group report of their discussion about their experience. The presentation of groups was digitally recorded, transcribed and then analysed.

This section has offered an outline of the three tasks undertaken in third phase. The next section summarises the findings from the interviews in the Netherlands while the following chapter outlines the findings from the use of the teaching materials in Pakistan.

10.5 Analysis of Interviews

This section presents the analysis and findings of the interviews conducted in the Netherlands. These were conducted in English and the interview schedule covered four areas: the nature of systems-thinking, biology education and systems theories, application of systems-thinking to biology education; and the impact of systems-thinking. Under each section, a summary of the interviewees' views is given with some short indicative quotations. The specific contribution of interviewees is denoted by numbers.

10.5.1 Nature of Systems-thinking

Three aspects related to the nature of systems-thinking were covered: its definition, systems-thinking as general and higher order ability and also requirements of systems-thinking.

The interviewees discussed the definition in general and then in the context of biology education. All accepted that there is no overall definition of systems-thinking. This is consistent with what Ossimitz (2000), Assaraf and Orion (2005) and Kali et al. (2003) have reported. Respondents reported that the difference in the elements of systems-thinking depends upon the type of systems being dealt with: political systems, social systems, economic systems, biological systems and technological systems. The definition also depends upon the educational level of the person responding to the questions. Nonetheless, they agreed that the common element in all the definitions is that systems-thinking involves 'relational recognition' (5).

With reference to the general definition of systems-thinking, it was stated that, *'systems-thinking is that you are able to think in the whole picture of system' (5).* This means that it is the ability, or perhaps a deliberate effort, to think about the components and processes of the system as linked and connected: hence, systems-thinking may be thought of as a mental framework. Such views have been expressed by Smith (2003), Senge et al., (2000) Checkland (1999), and Capra (1997).

In the context of biology education, different notions and concepts of systems-thinking were mentioned. For example it was stated:

> *'Systems-thinking is being able to link the biology concepts to their levels of organisation and being able to relate these components at each level of biological organisation and make the links between different levels of organisation: vertical thinking and horizontal thinking'* (4)
>
> *'It is the ability to understand the interaction of different flows and energies in the biogeochemical cycles'* (2)

Overall, the following themes can be identified from their comments about systems-thinking in biology education:

Systems-thinking in the context of biology education is

- Set of concepts about open systems
- Categorising object
- Understanding links
- Understanding interactions
- Understanding system's structure
- Retrospection and prediction

The interviewees' opinions about systems-thinking revolved around certain concepts about open systems which have emerged over the years in the form of systems theories. Most of them described systems-thinking as a set of concepts about biological systems. Some basic elements of systems-thinking required by school children learning biology were also mentioned. These were the categorisation of components, objects, and organisms, on the basis of structure and function. In the interviewees' opinion *structured based systems-thinking* and *function based systems-thinking, vertical thinking, horizontal thinking* and *cyclic thinking* could be recognised as elements of thinking required at different educational levels in biology lessons. However, the central idea of all types of systems-thinking in any context is the search for links and connectedness. The interviewees' opinions presented in section 8.6 also reflect that systems-thinking requires relational recognition. This is consistent with O'Connor and McDermott (1997), Richmond (1993, 1994) and Ossimitiz (2000, 2001) when they discussed systems-thinking in general.

Systems-thinking as an ability was discussed. Two points of views were noted: systems-thinking as a general ability and systems-thinking as high order ability. Firstly, it was stated,

> *'it is a kind of a general ability because we all try to make sense of the world'* (4).
>
> *' ...the capability to understand the social systems will be a kind of general ability that some people acquire naturally without having formal training... by experience or by implicit learning...'* (2).
>
> *'in daily life people speak about political, economic systems and it has the meaning of some aggregate of components belonging together'* (6).

From these statements it can be seen that the respondents believe that almost everyone has *some* ability to conceptualise systems in the social, political and economical context. People have developed systems-thinking in these contexts and have an understanding about the relatedness of different components without any training.

Similarly, in the context of education, it was noted that,

> *'Systems-thinking is a general ability...little children already do it...they see a lot of round things and they know that they are circles '* (5).
>
> *'Even secondary school children sometimes have an understanding of inclusive relationships ...that may be regarded as beginning of systems-thinking'* (6).

It can be inferred that systems-thinking is present in its most rudimentary or embryonic form in children and school pupils. However, it was suggested that the quality of systems-thinking probably differs according to the level of education and quality of teaching.

Apart from being a general ability, it was also reported as high order ability. It was told that in biology, it becomes a higher order thinking skill because it requires both a general element of systems-thinking (relational recognition) and a specific understanding of the structure of the biological systems. At more advanced levels it also needs specific knowledge and tools such as mathematics or computing.

It was suggested that,

> *'It becomes a learnt competence which is developed and learnt by doing it and using the tools necessary in assisting the thinking'* (2).
>
> *'...several forms of systems-thinking in the domain of social science, technology, biology and geography...some basic idea you can find in everyday life. It has particular meaning in several scientific areas'* (6).

Most of the literature also mentioned systems-thinking as a high order thinking skill or ability; however, Dornor (in Ossimitz, 2000), Sheetz (in Senge et al., 2000) regards it as closer to common sense and thus a general ability.

In the light of the views presented in section 8.6 and also the opinions gathered from literature presented in section 4.3, it is noted that systems-thinking has been described as a mental model, a way of thinking, a set of principles, a set of thinking skills, a set of tools, as a product, a procedure and process. It is suggested that the labelling of systems-thinking as general or higher order ability is connected with the type of definition given by the respondents. It is noted, that when the respondents defined systems-thinking as a mental framework or a way of thinking (soft definition), they labelled it as general ability. However, when a variety of skills, activities and tools were talked about (*hard* definition), it was labelled as higher order ability. Similarly, when simple systems are being considered with small number of components and linear or non linear connections, then thinking is believed to be a general ability. However, in the case of biology where complex systems are involved, it is considered as higher order ability. Social systems are also complex. However, such systems are much more accessible. When a system cannot be experienced or is not easily accessible, then its study requires higher order ability. It demands many skills and much specific knowledge.

Experience was identified as an important factor on which systems-thinking, generic and specific, is dependent. It was stated, *'...experienced people tend to relate things to each other more easily than un-experienced ones* (6). Based on experience, systems-thinking was regarded by some as intuitive. It was stated

> *'It is intuitive because intuition is something you have experienced so many times so you get an implicit notion from your experience. It is not reflected so you can not perhaps verbalise in a correct way. It is something you know from experience that things work together and that the things depend on each other and ... in that way it is not instinctive but learnt from experience'* (3)

However, it also has been reported that one needs, *'support to become a systems thinker...the teacher or trainer has to bring all those elements together'* (1). It requires training: '*...experienced biologist are , implicitly, very good systems thinker but secondary school biology students are not good at it and are needed to be taught...*' (6). By the respondents, a number of factors were identified as being involved in making an experienced biologist a better systems thinker than a biology student: *conceptual knowledge* of certain area; secondly; *cognitive skill* so that the person can relate things together; *specific skills* such as mathematics and computational skills may also be needed. Similarly, one should be *willing to engage* in relating and linking the pieces of information together. It all shows that systems-thinking requires a combination of knowledge, cognitive ability, skill, experience and an attitude. Similar ingredients of systems-thinking were reported by interviewees in section 8.6 and also in literature for example Hogan and Weathers (2003) and Berieter (in Hogan & Weathers, 2003).

Systems-thinking was regarded by the respondents as high order as well as a general ability. It requires a number of elements so is a set of abilities. However, the elements of the definition differ from one context to the other. The quality of systems-thinking in educational context was reported to be associated with the level of education and quality of teaching.

10.5.2 Systems Theories and Biology Education

In an educational context, there are many educational models. These have been derived from observation and empirical evidence and can be very useful in offering insights into how learning takes place. There are certain theories which do not talk about the way the students learn and the way teaching and learning can be improved and enhanced. In the interviews, respondents were asked about the educational importance and the utility of these theories (systems theories) for designing biology education. From interviewees' responses, three things have been noted: what these theories reflect, for whom are they useful and what educational insights they provide.

Reflection about Biology Domain

All the respondents referred to three system theories: general systems theory, cybernetics and systems dynamics. They referred to these theories when reflecting on the definition of systems-thinking in biology education. A summary of respondents view is presented below. These three theories talk about different aspects of living systems. It was stated

> '*...the general systems theory throw light on the structure and nature of the systems, cybernetics talks about how does the system regulate and systems dynamics talks about the evolutionary aspects of the open systems*' (4).

Reflection about biology domain

Multiple phenomenon of scientific research
Nature of biology knowledge (biological systems)
- Nature of system (nested nature)
- Structure of system (levels of biological organisation)
- Regulation of system (interactions)
- Evolutionary aspects of biology
- Dynamic nature of system
- Biological thinking (systems-thinking)

These theories talk about the nature and structure of the biological systems and the type of thinking required to study such systems.

Utility of this Knowledge

Although these theories do not offer explicitly any educational or pedagogical insight, their relevance for biology education has been recognised. For instance, it was stated that the fundamental concepts would help biology students to bring coherence and to understand complexity involved in biology. It was stated, '*It should be considered as an important part in biology teacher training*' (3). However, only the introduction of the major concepts was suggested (6). It was suggested that these concepts would help in training future teachers about the nature of their discipline so that they could teach the subject accordingly. Chen and Stroup (1993) have also given such an opinion. It was also suggested that, *'the fundamental concepts about the discipline ... must be known to the students, whether they are studying biology or getting ready to teach biology'* (3). Similarly, Johnstone (1991, 1999) has emphasised the importance of knowing the nature of the message (knowledge) to be presented to the learner so that teaching could be designed accordingly.

Pedagogical Insights

Some educational insights, derived from the analysis of the responses have been formulated as pedagogical principles and are presented following:

Principles for teaching biology

(1) Keep in view the nature of the systems (nested, open and dynamic nature)
(2) Keep in view the structure of the system (levels of biological organisation, interrelation)
(3) Teach without slicing biological themes by biological levels
(4) Teach keeping in view the complexity of the system
(5) Design educational content so that levels can be distinguished
(6) Teach for biological thinking (systems-thinking)

From the discussion with the interviewees, it became very evident that biology education has to talk about the nature of the living system formally and students should be shown the open, nested and dynamic nature of the living systems. Chen and Stroup (1993), Hmelo et al., (2000) criticised traditional education for avoiding complexity and presenting structural elements as a series of definitions. It has indicated that systems have to be presented the way they are, in reality, complex and dynamic. To show the dynamic nature of the systems, it is important to offer dynamic models and computer simulation to the students as a demonstration of the nature of the systems because, *'at certain points you can no longer put all details in your model'* (3). Recently, many studies have shown the importance of simulation for teaching the dynamic nature of the system (Wilensky & Resnick, 1999). It was told that the structure of the system has to be made known to the students and also the interrelatedness of the levels has to be shown to them by, *'going up and down between the levels of biological organisation...look at what are the things really interrelate, that is the way to look at coherence'* (3). Chen and Stroup (1993), Kapteijn (1990 in Lijnse et al.) Jacobson & Wilensky (2006) shared a similar opinion.

It was also identified that, *'one should not separate biological themes about biological levels'* (6). Thus, a link has to be made between different phenomena from different levels. For example, cell division has to be taught in conjunction with reproduction and heredity. It was added by the respondents that they should not be treated as two separate phenomena from two different levels as they are often taught part in cell biology and part in genetics. A link has to be developed between them to bring coherent understanding. It was also added that,

> *'Teachers have to be aware that they use implicitly lots of concepts from different levels of biological organisation...'* (1)

and hence was suggested that, to

> *'make it explicit that you use different concepts from different levels... you can design your educational material in that way that you can distinguish which level of organisation the content is related to'* (1).

This suggests that students must be told from which level the information or phenomenon is being explained.

Teaching revolving around these principles is described as systems-based education which can enhance students' systems-thinking and their understanding about the phenomenon. Systems-based biology education was also considered as a model for developing systems-thinking in the students.

These principles for teaching biology reflect the findings of studies by Knipples (2002) and Verhoeff (2003), Chen and Stroup (1993), Hmelo et al. (2000).

To conclude, the importance of systems theories for biology education has been reported in explaining the nature of the biological systems and giving an indication to design biology education accordingly.

10.5.3 Systems-thinking and Biology Education

Two basic questions about the use of systems-thinking in biology education were considered: firstly, *why do we need system thinking in biology education* and, secondly, *what is the best way of bringing systems-thinking in biology education.*

Looking at the first question, a summary of the views of the interviewees is presented.

Need to use system thinking because of

(1) Complexity
(2) Overload of information, terminology and processes
(3) Lack of coherence between different biological concepts
(4) Lack of coherent understanding among students
(5) Necessity of understanding human interaction
(6) Necessity of structuring biology content

The interviewee noted that biological sciences are using the systems-thinking idea extensively as an attempt to understand the complex nature of living systems. And it is hoped that systems-thinking would help to understand the complexity of the world around.

It was suggested that biology is regarded as a discipline of isolated information and fragmented concepts and systems-thinking was identified as a unifying factor. This might result in coherent understanding. It was stated that,

> *'You need to have some kind of coherence between different concepts. It is more or less trying to bring coherence in all the fragmented concepts ... systems-thinking is an important tool in reaching that'* (4).

Apart from this, systems-thinking was considered to be important to understand communication and interaction among people:

> *'... Systems-thinking might be useful both for the interaction side of biology education and also for biology content ...systems-thinking could be used for selecting and structuring the biology content'* (6).

Overall, the argument was made that systems-thinking is needed to organise and structure biology education to bring coherence to understanding and also to comprehend the complexity as well as understand human interactions.

Secondly, regarding the best way to bring systems-thinking in education it was suggested that it is difficult to teach about systems-thinking on its own. Systems-thinking needs the context of some content; it can serve as an organising principle for any content. Any discipline can be used to illustrate systems-thinking in education, However, it was stated that, '*... biology is very appropriate subject for introducing systems-thinking and for the sake of student you would start with biology and from biology you will develop systems-thinking ...*'(6). The argument was made that biology might well be the subject through which systems-thinking could be introduced into the classroom.

Theoretical lectures on systems-thinking were rejected. It was suggested that,

> '*Systems-thinking should be grounded in biology content ...develop some kind of biological context where systems view or approach may still be implicit and afterwards based on biological knowledge you can develop may be in an explicit view on systems-thinking you can make systems-thinking explicit..., eventually systems-thinking should arise from biological content and you should of course arrange biology education how to reach and make systems-thinking explicit*' (4).

Both implicit and explicit ways to introduce systems-thinking were advocated.

A narrative approach was suggested as a way to introduce systems-thinking in biology education:

> '*... It helps you to tell the biological story or the story of sociology of society, so it is a way of ordering the different facts and concepts and putting them into perspective*' (3).

From their views it was clear that the use of systems-thinking was seen as a way of teaching and not a way of adding content. It was stated that systems-thinking has to be a part of *all* aspects of biology education. The interviewees were explored how to design systems-based biology text, activities or questions for the students and also what to involve in systems-based assessment. The interviewees' opinions in this regard are presented below.

Systems-based biology content (text)

Views were expressed that there is a difficulty in developing a standard structure for systems-based content because systems-thinking does not define how to organise and structure the text in same way. For each lesson it has to be decided what is to be taught and achieved and what elements of systems-thinking are needed. For example, for a topic from ecology and a topic from genetics, the elements of systems-thinking will differ but there would be the same principles behind to show things linked. Perhaps, cyclic thinking and horizontal thinking can be included in ecology and vertical thinking (level thinking) and horizontal thinking for many topics in genetics.

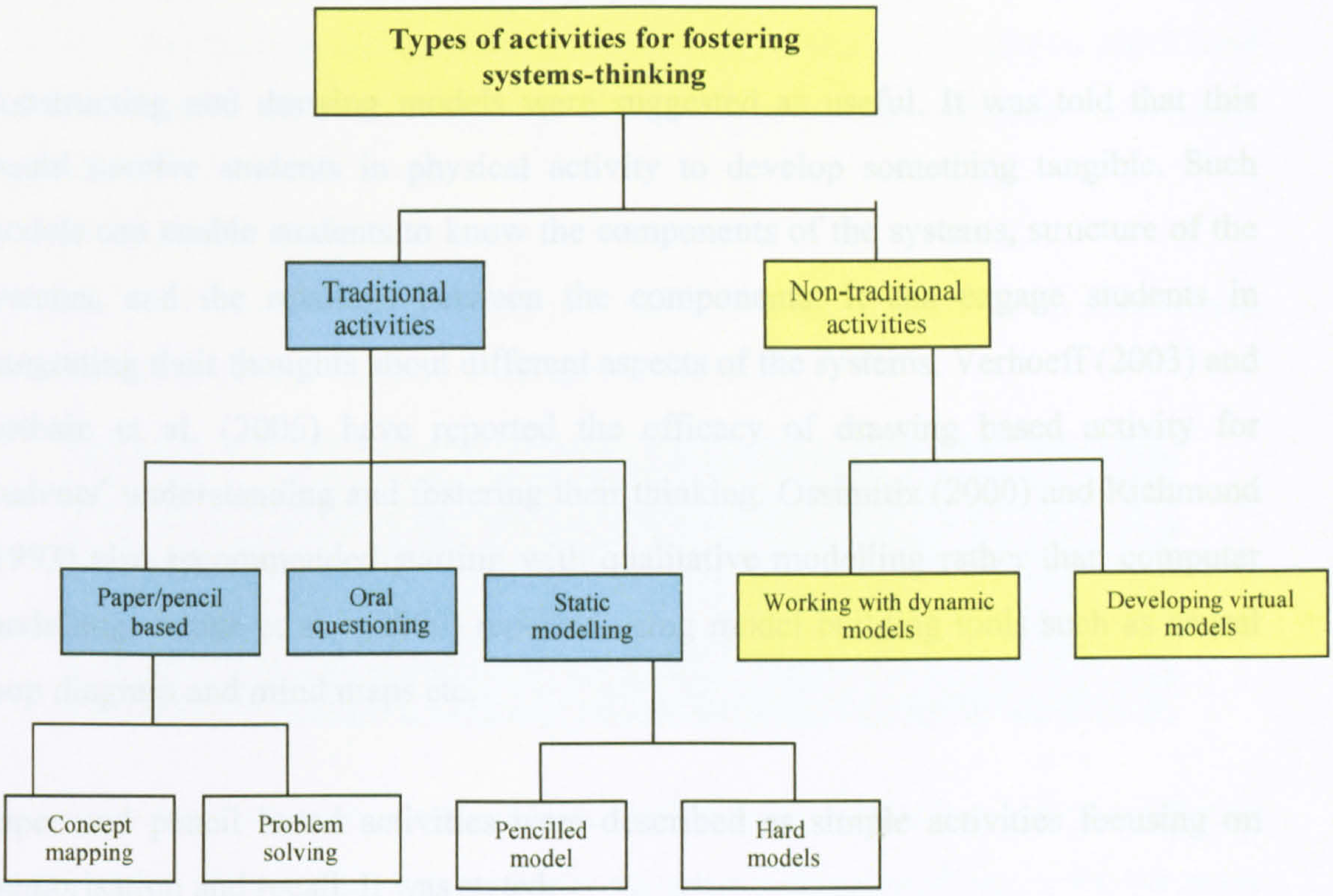
However, in the light of interviewees' opinion some principles have been formulated which can be regarded as general principles for structuring the biology text:

- The levels of biological organisation which are to be included in the lesson should be explicitly expressed.
- Content should be organised according to the levels of biological organisation, not haphazard information from different level.
- More than one level of biological organisation should be included to show links and connections between different levels (vertical links) and components (horizontal links).
- Explanations should be started at the concrete level (organisimic level)
- The learner should be taken up and down on different levels of biological organisation (yo-yoing).

Many of these principles have been advocated by the other researchers as well (Chen & Soup, 1993; Knipples, 2002; Verhoeff, 2003; Jacobson & Wilensky, 2006, and Smith, 2003).

Systems-based teaching and learning activities

Secondly, the interviewees were asked to express their opinion about designing systems-based teaching and learning activities for facilitating learning and assisting and engaging students in systems-thinking. A classification of activities which emerged based on the interviewees' opinion is given below. Most of the interviewees were in favour of non-traditional type of activities in the class room for example developing computer based models and also working with the virtual models.



It was noted that the type of activity to be used depends upon different factors: the objective, the aspect of the system to be highlighted and also the age of the students. Computer game-like programs have been suggested as useful if the dynamic nature of the system has to be highlighted. For example, It was told,

> '*...ecosystem is always the static concept and again same with the concept of cell... it is worthwhile for students to have a dynamic picture of eco systems ...and that exemplifies the dynamics nature of biological systems* ' (2).

Similarly, it was responded that relationship and interaction between different elements of the system and structure of the systems can be understood by the help of such models. Apart from using soft models, a strong opinion was recorded that *'they should be actively involved in the process of modelling...'* (4). Wilensky and Resnik (1999), Richmond (1991, 1993) and Ossimitz (2000) also hold the similar opinion. However, it was told that developing computer models at secondary school level and even at first university level, is too early because first students need to understand all sorts of things about a system and then can develop an abstract model.

Constructing and drawing models were suggested as useful. It was told that this would involve students in physical activity to develop something tangible. Such models can enable students to know the components of the systems, structure of the systems, and the relations between the components. It can engage students in integrating their thoughts about different aspects of the systems. Verhoeff (2003) and Rotbain et al. (2005) have reported the efficacy of drawing based activity for students' understanding and fostering their thinking. Ossimitiz (2000) and Richmond (1993) also recommended starting with qualitative modelling rather than computer modelling. Senge et al. (2000) reported using model building tools such as causal loop diagram and mind maps etc.

Paper and pencil based activities were described as simple activities focusing on memorisation and recall. It was stated,

> '*... I am not convinced about simple paper pencil based question activity. I'm searching for more involvement of students... I'm interested in higher order ways of thinking and acting, and I think it is necessary also because systems-thinking is complex off course and ..., you do not learn systems-thinking if you are just recalling some definitions'* (6).

Of course, simple questions asking for mere recall of factual knowledge are not challenging, though they are important from educational perspective. Smith (2003) and Hogan and Weathers (2003) have advocated the use of complex situation to evoke sophisticated and complex ways of thinking.

Teachers were recommended to model systems-thinking for the students:

> *'It is very important the type of questions that you ask and that you exemplify to the students ... teachers should be a model of systems-thinking... It should not take much time in asking question how does this relate to another level of biological organisation, or can you predict now that is the yo-yo thinking...'* (3).

The respondents believed that the teacher has to be engaged in systems-thinking and that this should be reflected in the teaching, especially the way questions are posed. Smith (2003) has strongly advocated and recommended posing systems-based questions, emphasising on searching for relationships. Similarly Knipples (2002) and Verhoeff (2003) used and suggested the problem posing approach for biology teaching.

In the light of interviewees' responses, the following criteria for systems-based teaching and learning activities have been formulated.

Criteria for systems-based learning activities is to engage students

- To look for dynamic interaction if it is needed
- To look for the effects of change in one variable to that on the other variable in the systems in case of simulation.
- To seek for relationship between components of different levels
- To seek relationship between the components of the same level
- To predict and retrospect about the phenomenon from different levels.

The activities which engage students in complex ways of thinking, evoking different abilities and skills, are the ones for fostering systems-thinking ability. Even the paper and pencil based activities have the transformational power if used appropriately.

Assessment and systems-thinking

Thirdly, the interviewees were asked to express their opinion about assessment of systems-thinking. The need for developing a new battery of questions for assessing systems-thinking was advocated. This does not imply that traditional testing has to be rejected. It may be very important to make sure that learners have the details of factual knowledge. They identified that there was a problem associated to measure thinking. Similar difficulties in measuring systems-thinking have been mentioned by Ossimitz (2000) and Hogan and Weathers (2003). From the respondents' opinion it appeared that both the formulation of questions and the way of assessing answers may be important.

Formulation of Questions. In looking at the formulation of questions, a number of different possibilities about assessing systems-thinking were stated. It can be deduced that, if systems-thinking is to become the students' way of thinking, then the presentation of complex context involving different levels of biological organisation and posing complex questions has to be important and should become a regular educational practice in terms of assessment. Similarly, it was suggested that students should be involved in converting text into schematic or diagrammatic form. Such text and questions have dual purpose and can be used both as a medium to engage and enhance students' thinking and also to assess their systems-thinking. Klieme and Maichle (in Ossimitz, 2000) have used such complex text-based scenarios for measuring systems-thinking.

It was added that students should be made aware about how people express systems-thinking. For this purpose, it was suggested that they could be given stories, or shown videos or discussions and then they asked to identify who was systems thinker and why. Again, it was believed important to give them questions which would allow them to think in a systems way.

Systems-thinking was stated as a complex way of thinking having a number of factors involved. It was agreed that there is a need to operationalise the defintion in the context. Once the elements of systems-thinking are agreed upon then it is possible to formulate the questions to assess these factors or elements of systems-thinking by using all types of existing questions in an adequate setting. In this regard Hogan and Weathers (2003) have also reported a difficulty of measuring different elements of systems-thinking working together simultaneously.

It was stated that the variety of questions is important and, that perhaps, open ended questions are important for assessing systems-thinking. Questions are needed which will make students elicit the information from their memory to produce an answer where they have to connect ideas together. Different types of questions make allowances for different students' preferences. One student can demonstrate their abilities by writing while another prefers drawing, while others like neither writing nor drawing but discussion (5).

The type of tasks mentioned by the interviewees for assessing systems-thinking included mostly answering open ended questions: essay, diagrammatic representation and mind maps. However, it was mentioned that all the other types of questions can be used in an adequate setting.

Evaluation of Answers. Although the formulation of questions is an important issue, the way marks are allocated may be even more important. It was suggested very important for the assessor to map the answer before hand to count how many links were involved to see how they relate and to explain the phenomena from different levels (5). It was also pointed out that the kind of statement and the way people word and argue may reveal the way they think (4).

The evaluation of the answers for assessing students' systems-thinking has been regarded as difficult but not impossible. Perhaps the key is to see how answers to questions can be analysed so that evidence of systems-thinking can be gained. It is inferred that the criteria might include the identification of which level they have provided information, which level has been missed, which element from a level has been missed, how many links have been made, and probably and perhaps how strong the links are etc.

It was stated

> *'in secondary school, students are willing to do what you want them to do because they know that they can get good grade when they do it like this way and they should be familiar with the kind of questions and also more importantly what is expected from them...when you do not ask for links and they are not used to do it... and may be it is a good exercise for them to have activities which help them to think about it...and then in the real exam they can do it by themselves and you do not have to ask for it in the question'* (5).

It talks about students, their willingness to think in a given way, teachers and their expectations, and also the issues related to assessment of what has been taught. It also brings into consideration the kinds of questions and classroom exercises which may be important. It indicates the powerful influence of teachers. It identifies that it makes sense to make students aware what types of answers are expected from them and then evaluate them on the criteria of expectation.

In conclusion, all aspects of biology education have a capacity to foster system thinking and also to employ systems-thinking as a teaching and learning tool for teaching and enhancing understanding.

10.5.4 Impact of Systems-thinking

The impact of systems-thinking on students' learning, on their immediate life outside the school and on the society as a whole was also explored.

Impact on students' Learning

A summary of respondents' view about the impact of systems-thinking on students' learning is presented below.

(1) It will enable students realise the complexity of the living systems.
(2) It will be helpful in making them think dynamically.
(3) It will make them aware of the need of knowing more to understand.
(4) It will enable them to ask analytical questions.
(5) It will develop coherent understanding

Firstly, all the interviewees agreed that the most immediate impact of systems-thinking would be seen in the classroom learning. It was stated; '*It will give them a better feeling about the complex relationships and complex system....* (6), it would also enable students '*to think dynamically about biological systems rather than statically*' (6). Similarly, '*It will help them to develop coherent understanding and will make them scientifically literate citizens*' (1). It was also stated:

> '*It will help students to assimilate knowledge in a meaningful way and will also enable them to ask relevant questions so as to generate or acquire new knowledge, ... it will provide them instrument to be active in the process of the acquisition of knowledge... may be they can ask questions every time what are they learning and*

> *why they are learning. So when they ask question they can say I know I need this because if I know this, I know how systems ... is, so if I do not have this factual knowledge so they immediately relate their need of knowledge... that's the enrichment of systems-thinking'* (3).

In this the respondent was arguing that probably scientific information without engaging with systems-thinking hinders scientific literacy. In this regard, Smith (2003) advocates the value of systems-thinking in the context of becoming responsible citizens. Similarly, many others have reported that systems-thinking is an intellectual tool for understanding the complex relations of the natural and man made systems in the midst of accelerated change (Richmond, 1993; Checkland, 1999; Hogan & Waethers, 2003). Knipples (2002) and Verhoeff (2003) and Smith (2003) have also reported the positive impact of systems-thinking on students' understanding.

Impact on Students' life outside School

Secondly, the opinion of interviewees about the impact of using systems-thinking on students' life outside the biology class can be illustrated:

> *'If you want to teach them systems-thinking in biology context and expect them to be systems thinkers in life outside biology. It will rarely happen'* (1).
>
> *'Just teaching systems-thinking in biological context is not enough... Transfer will not happen directly from biological world to social world'* (6).
>
> *' I do not think that when student learn a kind of systems-thinking competence in cell biology that they will directly relate it to all kinds of activities in the outside world... that's difficult... you always have problem with transfer of knowledge and re-contextualising problem'* (4).
>
> *'Of course all you learn inside school is important for development as a citizen but you should see it as a scientific literacy. I think it is very difficult to make a direct link between what you learn in school and what you do in your latter life outside. But there is a kind of scientific literacy which you can achieve in education'* (4).

There was not much optimism reported about systems-thinking' impact on students' immediate life outside the class room.

Although there was no denial about its impact, it was felt that systems-thinking in the context of biology education is not going to help students to think in a systems way in their life outside biology education. It was advocated that systems-thinking in the context of biology education may be a scientific literacy but to achieve literacy in the context of society requires more. There is the inevitable problem of transferability from one context to the other, a problem which is not unique to systems-thinking. However, the interviewees addressed ways to tackle the problem of transferability of systems-thinking from biological realm to societal realm. Some of the interviewees' original quotes are following.

> *'If you want students to be more systems thinkers outside the biology class then you have to tell them formally...see that society is like a system and you can think it in the same ways as levels and connections of biological world...application of systems-thinking for students outside the biological world would be a strange world. They must be taught formally' (1).*
>
> *'You need to have support from colleagues like geography ... transfer does not happen without doing anything. It should be part of the learning processes' (6).*
>
> *'So perhaps you should address systems-thinking in a lot of different context and perhaps outside biology to make it a kind of meta cognitive tools which student can apply in different context also outside biology. First, I would keep it within the biology' (4).*

They consider that it is highly unlikely that transferability of systems-thinking outside the boundary of the classroom will happen spontaneously. Students have to be taught formally and explicitly about the structural and organisational set up of social systems to make learners aware that this type of thinking can be used outside the realm of biology class. To see the impact of systems-thinking on students' life outside biology class, assistance from other discipline in school is needed such as social study, history etc. Senge et al. (2000) have reported some studies where school pupils' understanding of everyday life has been found to be affected, the way they looked at news papers and history, even their relationship with their parents. Smith (2003) has reported that teachers using systems-thinking to teach about urban ecosystems found that their thinking was greatly affected and their attitude was changed towards their own life.

The conclusion is that systems-thinking has to be developed in a number of disciplines before it becomes a habitual thinking.

Impact on Society

Thirdly, the potential impact of systems-thinking on a wider sphere of life, the level of society, was also explored. It was believed that the impact of systems-thinking could be far reaching:

> *'If they become politicians, lawyers, managers of a big organisation, they will be very well equipped to do their job because there are no simple answers for complex questions... perhaps the people are certain but the world is uncertain and science is uncertain. So my slogan is, we should be prepared to live with the uncertain science in uncertain world... I really believe in it that we should not give people the idea that things are simple. That's not the world we are living in but we should give them certain tools how to handle uncertainty. Otherwise you are preparing students for the virtual world which is not reality.'* (3)

The statement suggests that systems-thinking might equip people with a thinking tool to assist living in a complex world where life and people are linked more than ever. Every aspect of life has become complex. It is hoped that systems-thinking will help people to be comparatively responsible citizens in term of making sensible decisions keeping in view the complex array of network. This is consistent with what has been reported in literature about the wider impact of systems-thinking (Richmond, 1991, 1993, Smith, 2003; O'Connor & McDermmt, 1997).

It was stated that,

> *'It depends what you teach with the help of systems-thinking. If you use it as a means to make people more aware of the interaction between human agency and environmental degradation, eco systems, health, and then it could help making people more aware about environmental mechanisms and also the human role in them' (2).*

This belief suggests that to be aware about the connectedness of human activity with nature will make people realise the importance of the human role in environmental issues. Where systems-thinking is taught, it will bring benefit to that area of study. For example, if human interaction is emphasised then perhaps the impact will be on relations more and similarly if human and nature interaction is emphasised then the impact may be on solutions for environmental issues. Similarly, another point was made by saying:

> *'It is always good that people try to relate things to each other. I think systems-thinking is one endeavour or a way of making sense of the world and try to understand that there are different perspective on reality ... it is also sometime missing in the world that we have our own perspective on reality or some kind of issue and we do not think about other perspective of reality, religious or evolutionary perspective. It helps in understanding that there are different perspectives of reality.'* (4)

This seem to imply that systems-thinking will make people tolerant by making them aware about their linked position in the society with so many factors and probably will induce tolerance and acceptance towards those who hold different viewpoint. However, this is a bold assumption.

In conclusion, the interviewees generally brought almost all the important spheres of life including religion, politics, law, and environment, management, decision making, and human behaviour under the influence of systems-thinking.

10.6 Summary

Interviewees talked about the different concepts which have been used in systems theories while presenting their views about systems-thinking, such as open systems, levels of biological organisation, feed back loops etc. Overall, two types of systems-thinking were recognised. General systems-thinking was described as a general ability but domain specific systems-thinking as a higher order thinking ability. Higher order systems-thinking was believed to be a learned competence while the general systems-thinking was considered more or less intuitive. Systems-thinking was identified as an individual ability and as a collective ability in research/ professional activity or perhaps as a product oriented ability in collaboration with technology (systems dynamics). It was believed that there are different levels of systems-thinking. In less complex situations, it is a general ability but in highly complex situation it becomes high order thinking skill. The components of systems-thinking mentioned by the respondents were conceptual knowledge, cognitive skill, special skills (eg. mathematics, computation) and willingness. Hence systems-thinking has been regarded as a bundle of abilities.

Secondly, it was claimed that systems theories are not primarily pedagogical theories, but have implications for education as they offer insight into the nature of biological systems to structure knowledge to be delivered to the learners. It was argued that it was important for trainee teachers to have some appreciation of systems theories in order to understand the nature of the domain before teaching it. Some pedagogical insights (principles) for biology education have been derived from these theories.

Thirdly, the need of systems-thinking in education was advocated by the respondents because of students' incoherent understanding, a fragmented curriculum, teaching and learning activities and the complex nature of the biological systems. Somehow all these factors are interconnected, emphasising the need for systems-thinking. Moreover, it was argued that all aspects of biology education have the capacity to foster systems-thinking if they involve the principles of systems-based biology education. For example, where the reading material has been created to involve different levels of biological organisation and then make links between them by sequencing the material with explicit verbal and diagrammatical assistance, or where teaching and learning activities have been suggested which engage students in systems way of thinking either in the form of model building, exploring simulated models or answering questions. The importance of systems-based questions have been emphasised and of the teacher modelling systems-thinking for the students. Complex scenarios have been expressed as appropriate for engaging students in systems-thinking and also measuring their systems-thinking ability.

Finally, there was a view that systems-thinking has the potential to make people responsible global citizens. This is a bold claim and lacks any supporting evidence at the moment. Since it is claimed that the transferability of systems-thinking outside the boundary of classroom is unlikely to happen spontaneously, a deliberate effort is needed in the field of education to emphasise the importance and utility of systems-thinking explicitly and formally. It was added that systems-based biology education alone cannot influence students' thinking regarding all aspects of their life. They stated that the importance and utility of systems-thinking needs to be emphasised explicitly and formally, and that perhaps biology can be a pioneer in developing systems-thinking in education.

To conclude, the respondents believed that systems-thinking is a complex of abilities which, it is argued, needs to be fostered through formal education. Major concepts of systems theories were advocated for teacher training in biology education. All aspects of biology education were identified as being systems-based. The key, they said, rests with the teacher. It was believed that the use of systems-thinking can transform learning and understanding of biology, can have impact on learners' personal lives and thus have wider influence at social and global level but only through sustained educational efforts.

The next chapter presents the findings of the intervention conducted in Pakistan. It includes students' opinion about systems-based educational material.

CHAPTER ELEVEN

Intervention with Pakistani Students

There were three sources of information collected in the course of this intervention: intervention effectiveness survey, students' group presentation via semi structured interviews and students answers in the performance test. Only the information gathered from the first two sources is presented in this chapter. The findings from the third source are presented in chapter 12.

11.1 Intervention Effectiveness Survey

This section presents the findings of the 'intervention effectiveness survey' which contains a set of statements where students are asked to respond on a five point scale, following the Likert format. The aim was to find out how the systems-based teaching and learning material was perceived by the students. It offers a general descriptive picture of the opinions of the students about their experience with the systems-based teaching and learning.

The data obtained are ordinal and the response pattern for each question is presented as percentages for clarity. The fourteen statements of the survey questionnaire have been divided into four categories. Patterns of responses to statements in each category will be discussed in turn before seeking to draw some general conclusions. The responses from each of the colleges are shown separately but comparisons are not possible due to the small samples.

11.2 The Systems-Based Worksheet

Four statements explored students' reaction to the worksheets.

(a) I have not answered questions like this before

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	46 %	32 %	4 %	7 %	11 %
College 2	21	33 %	57 %	-	10 %	-
Total	49	41 %	43 %	2 %	8 %	6 %

Table 11.1 Data: question (1 a)

It is clear that the type of questions included in the work sheet were not a part of the regular class room teaching and learning practice for most of the students. In Pakistan, most of the time questions asked of students only require them to recall factual information and there is no concept of levels implicitly or explicitly in biology education.

(b) The questions in the work sheet helped me to visualise levels in a system

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	43%	46 %	7 %	4 %	-
College 2	21	52 %	48 %	-	-	-
Total	49	47 %	47 %	4 %	2 %	-

Table 11.2 Data: question (1 b)

There was an almost universal view that the nature of the questions enabled students to visualise levels in a system. This strongly suggests that systems-based questions have the potential to stimulate the ability to visualise levels.

(c) The questions in the work sheets helped me to understand the links between different levels of biological organisation

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	75 %	21 %	4 %	-	-
College 2	21	71 %	29 %	-	-	-
Total	49	73 %	24 %	2 %	-	-

Table 11.3 Data: question (1 c)

Again, there was an almost universal positive response to this question. Clearly, the systems-based questions posed in the work sheets were acting as scaffolding in guiding and leading learners in making them understand the links between different levels of biological organisation.

(d) The questions in the work sheet were helpful to make me think

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	54 %	39 %	4 %	4 %	-
College 2	21	71 %	29 %	-	-	-
Total	49	61 %	35 %	2 %	2 %	-

Table 11.4 Data: question (1 d)

There is a very strong response in agreement with this statement with more than 90% of the responses fall on the positive end of the spectrum. It should be an aim of education to develop skills of thinking and not just skills of recall. The questions in the worksheet have been successful for this purpose.

Conclusion

Smith (2003) has advocated the use of systems-based questions and called such questions a key to enhance and stimulate systems-thinking and students understanding. The findings here suggest that the questions were helpful in stimulating thinking and enabling to visualise in levels of biological organisation and understanding the relationship between different levels and components.

11.3 The Systems-Based Model

Four statements explored students' reactions to the systems-based model.

(a) *I found the model useful for visualising the organisation of the living world*

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	46 %	50 %	4 %	-	-
College 2	21	57 %	38 %	5 %	-	-
Total	49	51 %	45 %	4 %	-	-

Table 11.5 Data: question (2 a)

It is very clear that the students found this a most helpful way forward in being enabled to visualise the organisation of the living world.

(b) *The model helped me to organise my thoughts.*

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	37 %	44 %	15 %	4 %	-
College 2	21	67 %	29 %	-	-	5 %
Total	49	50%	38%	8 %	2 %	2 %

Table 11.6 Data: question (2 b)

One of the potential advantages of systems-thinking is to be able to see how things interrelate: the whole is greater than the sum of the parts. This requires considerable mental organisation skills. The students here certainly see the approach of the teaching materials as being a great help to this end.

(c) The model made me to arrange the knowledge in my memory

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	50 %	39 %	-	7 %	4 %
College 2	21	71 %	29 %	-	-	-
Total	49	59 %	35 %	-	4 %	2 %

Table 11 .7 Data: question (2 c)

It has to be remembered that these students have been brought up in an educational system which rewards memory work and recall skills. Therefore, any strategy which makes it likely to be more successful will be valued. Students would develop their own way of arranging the information in the memory but the systems-based model clearly provided a framework according to the organisation of the biological system.

(d) The model helped me to think in terms of levels.

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	68 %	29 %	4 %	-	-
College 2	21	71 %	29 %	-	-	-
Total	49	69 %	29 %	2 %	-	-

Table 11.8 Data: question (2 d)

It is very clear that the students here see the model as a powerful way to think in terms of levels, exactly as was intended.

Conclusion

The model seemed to provide a structured framework for the organisation of thoughts, knowledge and also for imagination. Chen and Stroup (1993) argued that details are rapidly forgotten unless placed in a structured pattern. Similarly, Hindal (2007) commented that recall success is highly likely to be related to the extent of meaningful links between ideas in long-term memory. Chittlebourough et al. (2005) recorded similar view of students about models '... *model is not always correct but it gives ideas how things work and visualise and create image in mind*' (p, 209).

11.4 Students' Own thinking

Three statements explored how students saw their own thinking being affected by the teaching units.

(a) I realise that thinking in levels can make genetics easier to understand

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	61 %	36 %	-	4 %	-
College 2	21	76 %	19 %	-	5 %	-
Total	49	67 %	29 %	-	4 %	-

Table 11.9 Data: question (3 a)

Their responses reflect a strong sense of realisation that thinking in levels can make understanding of genetics easier. It is an evidence about the importance of systems-thinking particularly thinking in levels in biology education therefore it needs to become part of the regular educational practice.

(b) I have developed a way of thinking in levels after these classes.

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	50 %	39 %	7 %	4 %	-
College 2	21	52 %	48 %	-	-	-
Total	49	51 %	43 %	4 %	2 %	-

Table 11.10 Data: question (3 b)

This may be optimistic but the students certainly feel that their thinking has developed after going through the systems-based teaching and learning experience. However, it is encouraging to look at responses because this is what was intended and was expected from students after going through the systems-based teaching and learning.

(c) I can apply this sort of thinking with the other topics in genetics

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	46 %	43 %	7 %	-	4 %
College 2	21	43 %	52 %	-	5 %	-
Total	49	45 %	47 %	4 %	2 %	2 %

Table 11.11 Data: question (3 c)

In this category, it is the only statement which has attracted less than 50% respondents for strong positive agreement. The possible interpretation is that probably students were not given a chance to use it in their normal learning yet. Perhaps, they were not really confident and comfortable to show their strong agreement. Nevertheless, it is encouraging to note that more than 80% respondents expressed a positive opinion that they could apply this sort of thinking with the other topics in genetics.

Conclusion

Students' views offer some evidence in the favour of systems-based educational material for making it easier to grasp the understanding in genetics. This view has been expressed in section 10.5.4 by the interviewees that its direct impact will be on students' understanding of the subject. It can not be commented how far the students went on developing and applying this way of thinking, however, for the current study the evidence is enough to show that if the students could realise a change in their thinking just after a week of involvement with the systems-based learning, then there is a strong optimism about its impact through sustained educational endeavours.

11.5 Systems-Based Teaching and Learning

Three statements explored this theme.

(a) *The idea of levels in genetics was evident to me for the first time when I completed these exercises.*

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	43 %	39 %	14 %	4 %	-
College 2	21	43 %	52 %	-	5 %	-
Total	49	43 %	45 %	8 %	4 %	-

Table 11.12 Data: question (4 a)

More than 80% of the students indicated unfamiliarity with the idea of levels before attending class. However, it cannot be assumed that that they were totally unaware about the concept of the levels. Perhaps they had a feeling but were not presented to them explicitly. It is also possible that as the names of the levels reflect the common terminology of biology domain like cellular level, organ level etc. probably the concept of level has been confused with the common concept of the biological terms.

(b) *I found the oral questions helpful for understanding the topic*

Group	***N***	***Strongly agree***	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
College 1	28	71 %	29 %	-	-	-
College 2	21	62 %	38 %	-	-	-
Total	49	67 %	33 %	-	-	-

Table 11.13 Data: question (4 b)

The responses here are remarkable in that this is the only statement among the 14 statements where 100% response goes towards the positive end of the spectrum. The questions were used to keep them involved in the teaching and learning process and also to make them to ascend and descend on different levels of biological organisation and has been very successful.

(c) *I would appreciate to have such level based work sheets for other difficult subtopic in genetics.*

Group	*N*	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
College 1	28	46 %	36 %	4 %	14 %	-
College 2	21	67 %	29 %	-	5 %	-
Total	49	55 %	33 %	2 %	10 %	

Table 11.14 Data: question (4 c)

The overall response in the favour of this statement is more than 80% and the degree of the favourability for strong agreement is quite high, which gives an indication that the level based activities were liked by them and would be preferred in future as well.

Conclusion

Overall, it appeared that the notion of level was new for the students but relational questions have been appreciated by the students. They also agreed to have such work sheets for the other difficult topics as well. Smith (2003) has advocated by saying that it is critical that the teacher consistently, repeatedly and intentionally include a systems perspective in lessons.

11.6 Summary

It is evident from the responses that most of the students have not encountered systems-based questions in their biology class. Systems-based questions may have helped them to understand links, to visualise levels, and to stimulate thinking. In addition, the approach has assisted in the organisation and arrangement of information while they indicate that it has helped them to memorise.

The important elements for developing understanding about living systems in the learning process have been found influenced and stimulated. This gives some confidence that the teaching and learning in the class room setting has a strong influence on the type of thinking students develop. In this case, the students say that their thinking has been influenced. This is remarkable given that it was only one experience of this approach. However, it has to be noted that teaching and learning in Pakistan is almost entirely the presentation of information in a lecture-type way followed by the expectation that the information will be memorised and, later, recalled in examinations. Thus, this approach will make a huge impact simply on the grounds of its novelty. In addition, the teaching materials had been carefully constructed in line with systems-thinking.

It is inferred from the responses that there is a strong sense of realisation among the students about the importance of thinking in levels, confidence about the development and intention of using this type of thinking to learn other topics in genetics. It was expected that the whole teaching and learning experience would stimulate students to adopt a way of thinking well suited for studying biology, and would enable them to use thinking in levels while studying biology.

It has to be stressed that the students liked the systems-based activities and would prefer to have them again. All this is very encouraging and the outcomes of this survey are now compared to those found from the students' interviews presented in the next section.

11.7 The Group Interviews

This section presents student's views about systems-based educational material. Students' discussion and their presentation of their collective opinion were bilingual, switching between Urdu and English. The interviews were recorded, translated where it was in Urdu, transcribed and analysed.

While the analysis was done group by group for both the colleges separately, their opinions coincided and, thus, the entire sample is treated as one. The interview schedule was semi-structured, with questions pre-categorised into four major themes; however, analysing the text gave birth to sub themes. Their views, under each theme with its sub-themes, are now summarised, supported by quotations. The identification of all the quotations is shown by group and college number such as g1c2 (group1, college 2).

The four major themes are the students' opinions about:

Systems-based reading material
Systems-based models
Systems-based worksheets
The whole experience of systems-based teaching and learning.

11.8 Students' Opinions about Systems-Based Reading Material

Two broad themes were discernible in the responses of the students: what was liked by the students and in what ways the materials proved to be useful in the learning process.

Elements of reading material liked: Firstly, quality presentation with colourful text, pictures and diagrams was appreciated. The material was attractive and appealing to them, and was appreciated. Secondly, the narrative style (personification, story, letter, movie like feeling), which is quite unusual for biology class, was quite liked by the students. Thirdly, they liked the active dynamic, talking text, with its easy language. Fourthly, the explanation of the phenomenon with levels was appreciated by them. Finally, the presence of obvious links in the content and 'yo-yoing' (going up and down on the levels of biological organisation) was liked by them. It is encouraging to note that the systems elements did not remain unnoticed in the midst of story and colourful material. They caught their attention and there was a positive feeling about using to a narrative style to teach scientific facts.

Usefulness of reading material: In looking at the reading material, it was found helpful in five different ways.

Usefulness of systems-based reading material in

- Focusing attention
- Development of the concept
- Rousing the their curiosity
- Handling information
- Yo-yoing

Firstly, they said it helped them to focus their attention, an essential for learning. They seemed to be emotionally engaged with undivided attention and one typical response was: *'We could feel as a new friend comes into class then he presents himself in the class and then we understand, and then these new things familiarise us with their name and background, we were taking it as a movie in front of our eyes' (g3c1).* It is well documented that when students are emotionally engaged they learn it better (Beck et al., 1995; Ianonne, 2001; Abrhamson, 1998). They indicated that their imaginations were stimulated: thus, *'we realised that something was happening in front of our eyes because it explained itself before us' (g5c1).*

They seemed to be suggesting that, in their imagination, they could see things happening in front of them in their mind as it was said that reading was like watching a movie (g2c2). The intangible was becoming real. Perhaps the more dynamic explanation livened up the biology lesson.

Secondly, they indicated that the materials had helped in conceptual understanding: *'it integrates the knowledge and information in your mind and develops concepts...' (g2c2).* This suggests that the text was bringing the information together, leading towards the grasp of the concept by the reader. The element of connectivity has been advocated by Knipples (2002), Verhoff (2003) and Beck et al. (1995).

Thirdly, they commented, *'It was just like reading a story book where you can not stop reading and want to know what happened in the end' (g2c2).* Thus, the reading material aroused their curiosity to know more. 'Need to know' is a very important principle of learning and teaching which has been found difficult to inculcate in students (Knipples, 2000; Verhoeff, 2003). Here, it is inferred that narrative style has the potential to evoke a sense of need for more knowledge and can be used to stimulate genuine interest.

Fourthly, it was noted that the, *'Story telling method helped us a lot...We liked going up and down in thinking and reading' (g4c2).* This suggests that they found it helpful in *yo-yoing*, moving up and down, as the content was guiding them on different levels and they were made aware of the different levels. It is important to be aware and know the position of the different levels of biological organisation while studying biology because it is useful to know where things belong before reading about them in detail. It is deduced that narrative is a versatile tool and it can be used to impart information, to emphasise a thinking pattern, to arouse interest. In this case, the narrative carried a systems-thinking element, thinking in levels, which has been called yo-yoing by Knipples (2000).

Finally, it seemed that the presentation of the material encouraged retention of information, integration and organisation of information. It has been reported in many previous studies that narrative style helps in the retention and recall of information (Beck et al., 1995; Abrahamson, 1998; McDrury & Alterio, 2003). And similarly in this case students responded: '*we pressurise ourselves to keep the information in memory. But this method we found easy and light. Here we studied in the levels and then we could keep the information in our mind.'(g5c1.)* It is not just the retention but also '*organisation of information in an organised way*' (g4c1). The phrase '*organised way*' can be interpreted as 'systems way' which in this case is 'in levels'. It is exciting that the students clearly noted organisation or specific patterns which they called 'organised way'. It was also expressed that, '*using the concept of level is the best way to teach biology*' (g2c2).

Several studies have focussed on the importance of the way information is stored in long term memory as a matrix of linked ideas (see Kempa & Nicholls, 1983; Reid & Yang, 2002; and Al-Qasmi, 2006). In the latter two studies, this was specifically linked to the solving of open-ended problems. It is the accessibility of links between ideas which seems to be critical. If information is stored in an isolated fashion, it is committed to memory in the form of separate 'islands of knowledge' (see Reid & Yang, 2002). It has been reported that such isolated information is hard to retrieve (Johnstone, 1997). It is reported that students often tend to store information compartmentalised (Kali et al., 2003). However, if the information is imparted in an organised way involving levels of biological organisation, it will be taken in by the students in that connected fashion. Because several ideas are linked, they tend to be seen as a whole and this is likely to reduce the load on their working memory space for further thinking.

Integration and organisation of information are part of systems-thinking in biology. Integration is a fundamental key element and an important step towards holistic or systems-thinking. It is very encouraging to know that reading material has been seen as successful in imparting integrated information, this being clearly noted by the students in the reading material. They felt that the presentation was sufficiently simple so that it could be easily handled by the students junior to them.

11.9 Students Opinion about the Systems-Based Model

Students' opinion about the systems-based models was also explored. During their presentation, two things emerged repeatedly. Firstly, they mentioned their opinion about the nature of the model and, secondly, they also mentioned how the model helped them in their process of learning.

Features of system based model identified: The idea of levels was clearly new to the students. According to them, they never heard of them and were never taught about it. It clearly reflects the fragmented approach to teaching and learning of biology. Students identified and were able to verbalise a number of features about the systems-based model:

Features of Systems-based Model identified

- Obvious presence of levels of biological organisation
- Links between levels
- Broad presentation of biology
- Presentation of the whole picture
- Presentation of the idea of open system
- Presentation of specific thinking pattern
- Systematic presentation of information
- Model as a main requirement for understanding biology

The presence of levels and the presentation of biology in a broad way indicate that students could sense that the way they were looking at biology was narrow. Similarly, systematic flow and build up of information, specific pattern of thinking, whole picture of the content and the properties of open system were recognised by them. Obviously, these features were incorporated deliberately in the system-based model. However, more importantly, they recognised levels as requirement for understanding biology and a prerequisite to develop understanding in biology learning. It is encouraging to find that almost all the features of a systems-based model which were intended to be explicit were identified by the students.

Usefulness of a system based model in learning: Students also commented on the usefulness of a system based model in the process of learning. Their responses are summarised below.

Systems-based model enabled students to

- See the whole picture
- Organise their thought
- Organise the information in systems way
- Develop their own mental models
- Think in systems way (specific patter)
- Visualise and imagine in a systems way
- Understand the content
- Recall of information for Answer questions
- Draw diagram in the test and work sheet
- Internalise the concept of levels of biological organisation and their links

Organisation of the information in a systems way and presentation of the whole picture are connected together. If information is not knitted together and presented as isolated then the picture does not appear. However, students have found the model useful because it offered the whole picture of the system under consideration. This is consistent with what was reported by Gilbert & Boulter (1998) that models can be used as a framework for holding the fragmented information together and it has been confirmed by the students as they said *'with the help of this model we could see the whole picture'* (g4c2). Students also found the model useful in answering the questions and in drawing a diagram in their work sheet and the test. This reflects the way a model can assist in gathering ideas together into a coherent whole.

The model was found helpful by the students to internalise the concept of levels of biological organisation and having such a frame work has assisted them to develop their mental models: '*it helped us to develop picture of the text in our mind*' (g2c2) and also '*by model we can organise our diagrammatic concept in mind*' (g4c1). In line with such expressions, Harrison and Treagust (2000) have reported an effective use of models in learning and teaching: the development and the manipulation of the mental models.

Students offered opinions about their thinking: '*it has changed our thinking... we want to use this type of thinking with the other topics as well*' (g2c2). This is also supported by reports of Mayer (1989), Treagust (2000), Gilbert and Boulter (1998). They have called models as "thinking tools" and system based model has given a framework for a number of things such as: thinking and imagination, presentation and arrangement of information and also in understanding the content given in the text.

Students were also positive about the potential usefulness of such models for developing understanding of the other topics in genetics and even to use the model in their examinations. Most of the comments made by them resonate with the observation that the model helped them in their learning processes by providing a way of thinking which is required for learning biology.

Some of the weaknesses of the model were also identified by the students. It was perceived as too simple and lacking in presenting the minute details of the sub-cellular levels. This is a valid observation but the model was developed with an intention to introduce the levels of biological organisation in a simplified way and minute details were not a focus of the units. Nonetheless, it illustrates an important point: the students wanted to see things in more detail: *'It would be better to picturise the levels... we would like to see what is happening at the molecular and cellular levels... should be in detail' (g5c1)*

It all suggests that in spite of these limitations, systems-based model has potential to help students learning and understanding in number of ways.

11.10 Students' Opinions about the Worksheets

How students handled the systems-based worksheets was also explored. Students expressed their opinion about the nature of the questions, why they found the questions difficult, what problems they faced in finding the answer and also in what ways the work sheets were helpful in their learning process.

Reasons for finding questions difficult: Different phrases about the nature of the questions were used; for example they thought that questions were *'difficult'*, *'unfamiliar'*, *'unique'*, and *'different'*, *'new'*, *'complicated'*, *'tricky'* and *'not straightforward'*. These expressions alone reveal a lot about the questions. However, the different reasons emerged about the difficulties associated with questions are presented below while the quotes from which they have been derived are given in the appendix.

Reasons for finding question in the worksheet difficult to handle

(1) No experience with such questions
(2) No mental readiness for such questions
(3) No facts testing questions
(4) No understanding of levels
(5) Too much information in question
(6) Requiring deep thinking
(6) Limited time

It is not strange that the types of questions which are unfamiliar initially are seen as difficult. However, the positive indication is that, in spite of their difficulty in the beginning, later on they were found easy and useful. Their mental readiness to perform any thinking task was expressed: '*Our mind was not ready to attempt such questions...Most of the time ... our teachers give us questions like define gene or genome, but in sheet the questions were different...*' (g4c2). However, students quickly learned to re-align their thinking: '*We read the first unit in the same old fashion and then questions in the work sheet were not of the type we used to do, so the questions in first worksheet helped us to realise how we have to read, so the second unit we did reading keeping in view the type of questions*' (g4c2).

This seems to be an open declaration that the questions made them change their thinking pattern and set the reading habits of the students because they read and think in line with what is expected from them. Thinking and reading patterns of the students are greatly influenced by the type of questions posed to them. This illustrates that, if systems-thinking is to be inculcated in the students, then there is need to pay attention to the questions because they silently but forcefully shape the reading and thinking patterns of the learners.

There is also an evidence that the questions were not of a reductionist type as students commented: '... *we normally do the question where we have to recall and reproduce but these questions demanded understanding. We could not answer just by reading them once; we had to understand the situation in the question before thinking about the answer'* (g3c2). They also commented: '... *but you asked about why and how so we had to think a lot'* (g5c2). Students clearly realised that they needed to have a different type of thinking to answer the question which required of them to think of small details to understand the big and complicated things: questions encouraged them to link smaller details with the bigger happenings. This is deep thinking – thinking for understanding. It is necessary to formulate questions which would challenge their understanding by demanding deep deliberate thinking. Indeed, the students used the term '*deep thinking'* for the type of thinking needed from them while dealing with work sheet and reading the systems-based material. Indeed, systems-thinking is deep thinking.

The amount of information in the questions was unusual for them. They indicated that, '...*There was a lot of information.... We had to think a lot of things about the questions before we could answer'* (g2c1). It is clear that the amount of information in the questions was unusually high and needed a lot of time to process it and they found that time available was not enough: '*Short time... had to think a lot... look and summarise in our mind and then we had to pick up the answer. We had to wind up lots of things while understanding the question'* (g3c2).

This raises question about the working memory. If the time given to them was extended then they might have had more time to process information, clarify ideas and thus, avoid the problem of overloaded working memory space. Almost every group thought that time provided was not enough and they needed more time to understand the questions. However, it is encouraging that question enabled them to see the whole picture of the system. It was said '*...We had to recall everything and we had to pick the related information and we found it difficult*' (g3c1). This allowed them to see the bigger picture, to be involved in deeper understanding and to bring ideas together. Some of the students realised that lack of understanding of levels involving biology made it little bit difficult to understand the questions but they found them easy and interesting later on.

It is encouraging to note that systems-based questions have been found helping students in their learning process in a number of ways. The questions have been found clearly different from the traditionally asked questions.

Reasons for finding answering difficult: Some of the more interesting quotes are presented below.

> *'Thinking was needed for answering the questions, it was not just by recalling, you had to think, and reasoning was needed. We had to think taking into account the level, then think and then answer... we normally do the question where you have to recall and reproduce but these questions demanded understanding. We could not answer just by reading them once; we had to understand the situation in the question before thinking about the answer.' (g1c2)*
>
> *'...we had to think a lot of things about the questions before we could answer....our mind set up from primary school till now, is different from the way you are trying to make us teach and learn, it is based on cramming. We had crammed everything But here we had to pick the main thing from the information and then we had to answer' (g2c1).*
>
> *' in answer only one piece of information was needed but for bringing that piece of information we had to recall a lot, almost had to look at the whole picture' (g4c2)*
>
> *'Because we already know what the question would be and what we would write for the answer. But here were not questions and no answer, it was a whole picture, you had to look at the whole thing and then had to pick the specific thing for answering. We had to go in depth. Normally, we copy and cram and there is no clear concept that how things work' (g3c2).*

Thus, the students found it difficult to answer, *firstly,* because questions and answers were unusually connected, *secondly,* because they had to look at the whole picture and then had to extract the relevant information for answering, and, *thirdly*, because it required of them a clear conceptual understanding because answers could not be written effortlessly without having focused attention and getting into deliberate thinking.

Their responses revealed much about the questions and the type of answering involved in their class room. According to them, for their examinations and tests, their answer is already prepared because they already know the nature of the question: explain, define, recall, etc. They are used to learning answers by heart and then reproducing them accurately. However, in the worksheets, the answers required were not the production of all the known facts about the phenomenon. They had to rely on their understanding because questions were not asking them to recall and write. That made them to think deliberately. Extraction of the relevant information was found bit difficult. That is why they were hesitant to write answers in the beginning.

It seems that questions and search for answers made them to bring the whole cognitive node ('island of knowledge': see Reid & Yang, 2002) from their long term memory to their working memory space and not the individual factual information. It was just like hovering over an island of knowledge to pull together the relevant pieces of information. Students found it difficult to recall everything. It is either because of the shortage of time as they stated previously, or because of the fragmented knowledge they hold as it was said, ' *unless the concept is clear, we could not answer the question'* (g2c2)

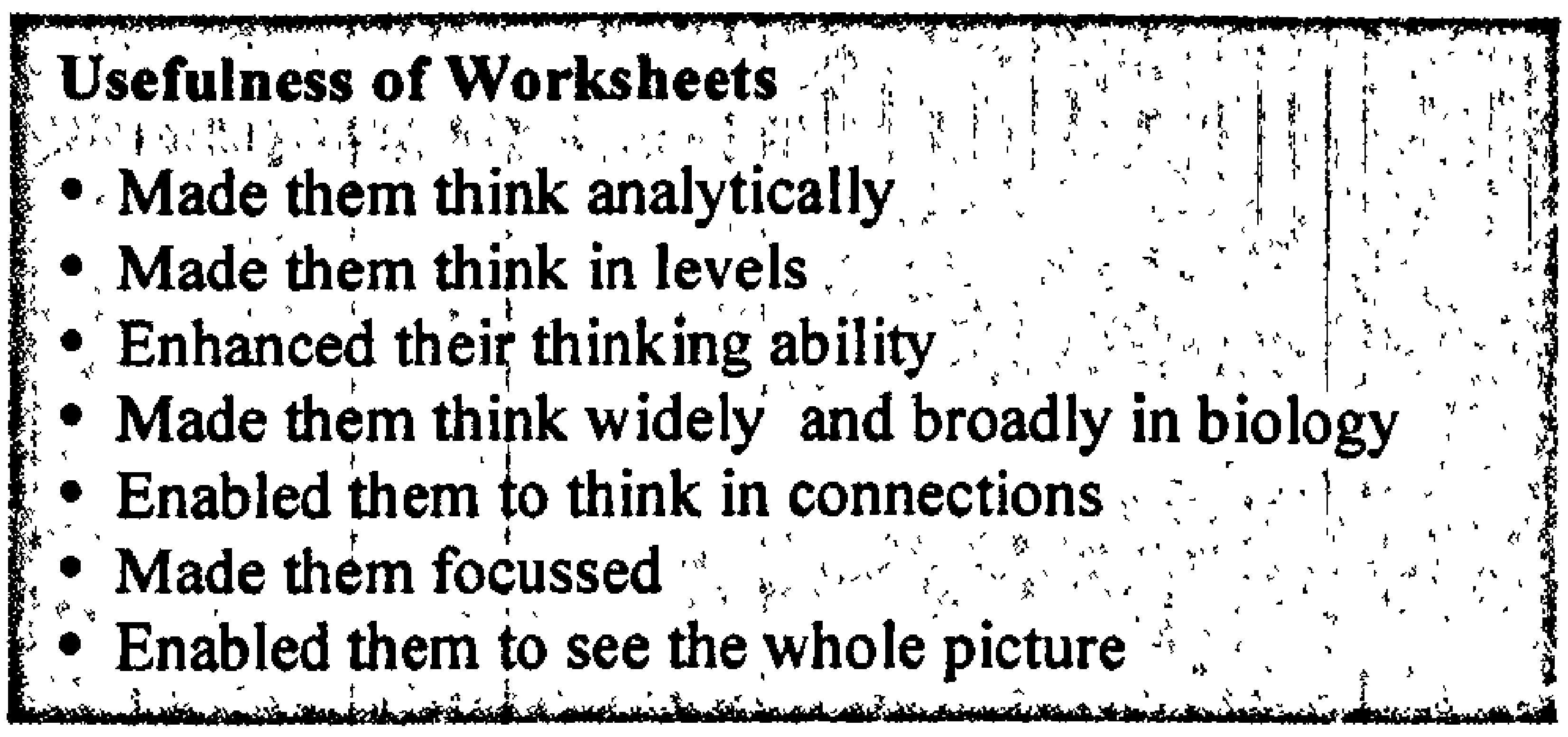
It might be inferred that one needs to have a holistic understanding of the concept to answer systems-based questions. If one has fragmented information in mind and, unless the concept is clear, one cannot even understand the question. Perhaps, each question was seen as a myriad of information or it could be seen as one picture.

However, it is encouraging that they were taken beyond the isolated, sliced information to look for the networks and a bigger landscape of biology knowledge and this survey of the wider picture involved them in systems-thinking where they had to think deeply about different details and their connectedness.

Usefulness of worksheets: The usefulness of the worksheets is apparent from the discussion about the systems-based questions and the search for answers. However, some of the following quotes also indicate the supportive nature of the worksheets in the process of learning in a number of ways.

> *'Questions ... made us to think not only for answers but also for questions...The main thing was that they made us to think about the topic into small steps to use our mind and memory. These minute and small steps made to use our mind and memory in order to understand the given topic... made us to think the large and complicated things' (g1c1).*
>
> *'The questions were related to each other, made us think in terms of levels' (g2c1).*
>
> *'Tremendous work sheet, it enhanced our thinking... it enabled us to understand the basic concept' (g4c1).*
>
> *'The questions have opened up or mind, made us to think so we liked them. They forced us to think deliberately... picture and models developed in our minds while we were reading the questions, we thought stepwise and we knew in our thought where we were because we could see the whole picture and actually we had to think about the whole picture before answering the questions '(g2c2).*
>
> *' They helped us in thinking widely on different aspects, our thinking capacity increased, we got much knowledge, and introduction of the level was new to us and the biological organisation helped us to understand the confusing questions '(g3c2).*

In the light of the above quotes, the following summary is offered about the usefulness of the work sheet.



Usefulness of Worksheets

- Made them think analytically
- Made them think in levels
- Enhanced their thinking ability
- Made them think widely and broadly in biology
- Enabled them to think in connections
- Made them focussed
- Enabled them to see the whole picture

The questions were effective because they encouraged them to think in a number of ways and most of them did not require just recalling an answer. Questions encouraged analytical thinking as they had to go step by step towards finding the answer. On the way towards finding answer, they could visualise the whole picture because small steps build up the whole ladder.

It seems that the questions engaged them in thinking in levels. The involvement of levels also made them know the context in the midst of wider biology. It is very clear from one of the statements: '... *we study cell and we start with cell and finish with cell... now we know and feel on what level we are and we descend gradually and then reach at cell level...'* (g5c1) which means it is a fragmented approach to teaching when there is no reference to the connectedness. Also, '... *now we know and feel on what level we are, we are studying this and we are on this level, so in this way we can easily understand and explain'* (g5c1). It means knowing one's position on the levels of biological organisation and being aware of levels above and below makes one see the things linked and connected and thus provide a context.

The worksheets seemed to encourage imagination. They felt they needed to have holistic approach towards understanding and thinking: it broadened their horizons to see and think beyond the fragmented and isolated pieces of information. The questions also required a focussed attention from the students because thinking about questions was found more important than thinking of answers. While thinking and trying to understand the question, they were in the process of preparing the answer. The connectedness of questions and answers made them attentive, focussed and to see the things in a coherent way.

11.11 Overall Experience of Systems-Based Teaching and Learning

Generally the opinion about their overall experience was quite positive. Thus:

> *'We were never taught in this way. The only source of learning is to listen to our teacher's lecture and read our book. We do not and are not engaged into any sort of thinking activity' (g2c2)*

They all stated that this way of teaching and learning was different from the way they normally go through in their class room; they liked and appreciated the systems-based teaching and learning; found it interesting, engaging. They appreciated the material provided to them in the form of reading booklets, models and activity sheets. In addition, they also realised and understood the significance of the material and also appreciated the hard work done in the production of such material. They found the idea of levels unfamiliar to them: *'The presentation of levels, their biological organisation and the idea of linking different levels was new' (g1c2, g4c2, g4c1).*

Very importantly, a very fundamental fact which students realised was that this way of teaching and learning has set a foundation of studying and understanding biology properly. It was commented: *'Teachers normally teach us whatever is in the book but do not teach the things what makes the basis of understanding' (g4c2).* There was also a suggestion regarding the systems-based teaching and learning: *'From our early days in school we were taught differently ... if it is introduced from primary classes then it will be very useful' (g5c1).* The last comment is very perceptive in that it is appreciated that type of thinking need to be developed consistently. Overall, these comments suggest that students have benefited from it and have deeply realised the importance of systems-based education, they regarded it, level of biological organisation, as a foundation to build the biology knowledge and understanding on it.

They also expressed their opinion about the way of lecturing and presentation. Some of the comments regarding the lecture delivered are following:

> *'Teacher explained the details in a systematic way...we liked that she started from the bigger level and then moved down to the lower level' (g1c2).*

> *'...Lecture, gripped our attention; we were very focused and we knew where we were going and what we were studying' (g2c1).*
>
> *'We liked the environment of teaching; it was open, friendly, interactive... ' (g3c2).*
>
> *'During her lecture, teacher was asking questions to make sure we understood and were with her; she took us to different levels involved in the topic and made sure we knew what level she was talking about' (g4c2).*

These are the educational principles to be practiced in the class room for effective learning. Although they found the teaching environment friendly and interactive, they also pointed out that the teaching session was quite long!

They also expressed in what ways the whole teaching and learning experience has helped them. Some of the statements regarding this are presented:

> *'It made us think and reason, in order to unite the scattered and irregular information and enhanced our learning sense and provided us a way to represent the whole thing' (g1c1).*
>
> *'Our power of retention was enhanced; quality of recalling information improved and we were made to think and reason' (g2c1)*
>
> *'It enhanced our power of thinking and sense of imagination; changed our way of thinking and gave us a new way of thinking' (g3c1)*
>
> *'It helped us in organising our thoughts; inspired us to know more about the topic and genetics in a new way' (g4c1)*

It is obviously clear that systems-based teaching of biology was new for the students and is clearly seen that it was a thought-changing episode for them. It has been argued in the literature that systems-based teaching approach to biology is important for developing a sound understanding of biology (Knipples, 2002; Verhoeff, 2003; Smith, 2003) and their responses seemed to confirm this strongly: there was a realisation that systems-based teaching and learning was not just new but also a prerequisite for studying and learning biology. It was also realised by the students that after just one teaching and learning session, a foundation had been laid for future learning.

The emphasis on levels provided them a focus and a way to know their position in the biological organisation while they are studying biology. Students' opinion also supported the view that teaching has to be started from something concrete: thus, they liked moving from higher level to the lower levels in the hierarchy of biological organisation.

The teaching session helped students in different ways in the process of learning: for example, their imaginations were excited; their powers of retention and thinking were enhanced; quality of recall was improved; they learnt to organise their thoughts and scattered information in the form of a whole. It is very encouraging to find out that the students appreciated that their way of thinking changed. All these aspects of the findings support the rationale behind the systems-based teaching and learning of biology.

To conclude, the students' beliefs in the form of their expressed opinion have provided evidence about the importance of systems-thinking to be used as a teaching and learning tool. It has been found that every aspect of educational material influenced students' learning process in a number of ways. These finding are consistent with the finding of the 'intervention effectiveness survey' present in sections 11.1-11.6 of this chapter.

The next chapter presents students understanding about the phenomenon of transposition revealed through performance test presented to them at the end of teaching session.

CHAPTER TWELVE

Exploring Students' Understanding

This section presents the type of questions included in the performance test, describes the analysis and explains the evaluation of students' answers.

12.1 Introduction

There were two types of questions involved in the performance test.

Closed questions: For such questions there was a predetermined piece of information required to produce an answer. However, it did not encourage an effortless recall of the information. Students had to relate a number of things for which deliberate thinking was required.

Open ended questions: The open-ended questions offered freedom to answer. Students were not bound to provide a specific piece of information. They could use one piece of information from one level or several pieces of information from more than one level. There were two categories of open ended questions: *fully and partially open ended.*

12.2 Purpose of Analysing the Answers

The test items were used as an analytical tool to have an access to students' understanding. Their answers were analysed in detail. The objectives of this detailed analysis were as following:

(1) To explore the quality of students' answers.
(2) To explore what test item students were good at answering?
(3) To explore what do students' answers reveal about their understanding?

12.3 Scheme for Mapping Answers

When evaluating the answers of the closed ended questions, students were scored for every correct piece of information. In addition, for the open-ended questions, the *complexity of an answer* (the completeness of the information) was investigated: every correct piece of information needed for a complete answer was taken into account, involving their identification of all the relevant levels of biological organisation and all the relevant components from these levels. It is understandable that the mapping of information in the written answer cannot be taken as an absolute measure of the complexity of students' understanding. These scores have been used as *indicators* of their grasp of complexity. The mapping scheme was used as an analytical tool and was named as *'the complexity indicator'*.

For evaluating the complexity of an answer, following scheme was prepared. For example, in question number 9 where students had to draw a diagram to show why and how the corn seed became speckled. Evaluation included all the information needed for a complete answer. Every column of the scheme was taken into account in terms of entering the information into the raw data sheet. A similar scheme was adopted for evaluating the answers to the other fully and partially open questions.

Information about levels				**Information about components**										**Information about model**		
Organ	Organelle	Mollecular level.	Expl. Levels	Nuclues	Chroromosoe	Gene C	Gene size	AC	DS	enzyme	Chromoplast	Anthocyanin	Proc.of transposition	Open ended	Hiearcy	Followed model

The percentage of information available in an answer was used as a measure of complexity in its crude sense. This measure allowed the answers to be categorised as one of the following categories:

(1) Complete answer if 76-100% information provided
(2) Less complete answer if 51-75% information provided
(3) Fragmented answer if 26- 50% information provided
(4) Very Fragmented answer if 0-25% information provided

12.4 Analysis of the Answers

Students' performance in the form of score did not just indicate the score for the right answer but it reflected how complete or fragmented the answer was. Students' answers were divided into four categories. The percentage of information provided for each answer was calculated and the answer was allocated to one of the four categories mentioned above. Apart from categorisation, a detailed analysis of the answers was conducted to probe which levels and the components have been most and least represented in students' answers.

The total test score of each student was also calculated and the percentage of their score was assigned to one of the four categories. Table 12.1 shows that few students offered complete answers, most being fragmented to varying degrees.

Table 12. 1 Categorisation of students overall performance in the test score

	Category 4	**Category 3**	**Category 2**	**Category 1**	
	(0-25%)	(26-50%)	(51-75%)	(76-100%)	
Total test score	***Very fragmented***	***Fragmented***	***Less complete***	***Complete***	N
College 1	14 (50%)	4 (14%)	10 (36%)	-	28 (100%)
College 2	6 (30%)	9 (45%)	3 (15%)	2 (10%)	20 (100%)
Combined	20 (43%)	13 (27%)	13 (27%)	2 (4%)	48 (100%)

Some students failed to answer all the questions. The missing data has tended to make the percentages in categories 3 and 4 rather high.

An analysis of the answers for each question is now considered in turn.

12.4.1 Closed Questions

For question 1, a pool of information was provided and the students had to pick up the relevant elements to group them into two categories. In questions 6 and 7 a skeleton of a word picture was painted and students were precisely told the type of information needed to fill it (see next page).

Closed questions

(1) The table below shows eight elements related to transpositions.
Divide the elements into 2 groups of elements, four in one category, and four in another.
(Use the numbers of boxes to show the groups)

Column A	Column B
1: Replicative transposition 2: Normal genome size 3: Human beings 4: **DS** (Transposable element) 5: **LINE & SINE** (Transposable element) 6: Corn seed 7: Bigger genome size 8: Conservative Transposition	**Group A** **Group B**

(6) Suppose you are given two genes responsible for **corn seed** pigmentation.
One of the genes carries "Ds" (transposable element) in it and showing a stable mutation, while the other gene is without Ds.
The presence or absence of element Ds is a source of information.
What would you deduce about the **phenotype** of the corn seed, its **genotype, and gene size?**

Fill in the details of your answer in the following table.

Gene	Phenotype	Genotype	Gene size
Gene 1 (carrying Ds)			
Gene 2			

(7) You are given purple and yellow *corn seeds*.
What can you deduce about the **genotype, gene size** and the **presence or absence of transposable element** in case of these corn seed?
Write your answers in the space provided.

Corn seed	Genotype	Gene size	Transposable element Yes/ No
Purple seed			
Yellow seed			

For question 1, the second category (less complete) was the modal category (table 12. 2). Only a small proportion (less than one fourth) of the students' answers was found to be complete. For question 6 and 7 a high proportion of answers fell into the *complete answer* category.

Table 12. 2 Categorisation of answers for closed questions

	Category 4	Category 3	Category 2	Category 1	
Closed Questions	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	*Less fragmented*	*Less complete*	*Complete*	
Q1					
College 1	2 (7)	-	20 (71)	6 (21)	28
College 2	-	1 (5)	15 (75)	4 (20)	20
Combined	2 (4)	1 (2)	35 (73)	10(21)	48
Q6					
College 1	3 (17)	3 (17)	1 (6)	11 (61)	18
College 2	2 (13)	5 (31)	4 (25)	5 (31)	16
Combined	5 (15)	8 (24)	5 (15)	16 (47)	34
Q7					
College 1	3 (16)	4 (21)	1 (5)	11 (58)	19
College 2	5 (26)	4 (21)	4 (21)	6 (32)	19
Combined	8 (21)	8 (21)	5 (13)	17 (45)	38

12.4.2 Partially Open-ended Questions

For questions 2a and 2b information was provided in the form of a complex scenario which was information rich. Students were expected to link all the given pieces of information to give some explanation about the phenomenon.

Q2 What can you explain with the help of the following information?

(a) Bacteria causing food poisoning are present in the intestinal tract of a patient admitted into a hospital. These bacteria contain insertion sequences in their genome. A bottle of medicine (antibiotic) is lying beside the bed of the patient which is Tetracycline.

(b) A patient suffering from lung infection caused by bacteria carrying transposon lying on his bed in a ward. A bottle of medicine, tetracycline (antibiotic, is lying beside his bed. It is the only available medicine to him and it is not proving to be effective as well).

In these questions students had to deal with the components belonging to different levels of biological organisation of two organisms (humans and bacteria). Although presentation of the information has set the boundary, students were not told what they had to pull into their explanation.

Question 2a: Overall, only a small percentage of students provided complete answer (table 12. 3). A complete answer is a reflection of wider thinking where all the given information in the question is connected. Only a small number of students' answers reflected the complete linkage between the pieces of information provided (between genome of the bacteria, the health of the patient, and status of bacteria and the effectiveness of the antibiotics).

Table 12.3 Categorisation of answers for *question 2a*

	Category 4	**Category 3**	**Category 2**	**Category 1**	
Partly open question	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	***fragmented***	***Less complete***	***Complete***	
Q2a					
College 1	11(44)	11 (44)	2 (8)	1(4)	25
College 2	4 (21)	5(26)	8(42)	2(11)	19
Combined	15(34)	16(36)	10(23)	3(7)	44

The detailed analysis of answers to question 2a (table 12.4) reveals that all the students mentioned the effectiveness of the antibiotic. This effectiveness was widely related to the killing of bacteria by more than 60% of the students. But effectiveness was not widely related to the status of the patient.

Table 12.4 Detailed analysis of question 2a

Components	**College number 1**		**College number 2**		**Combined**	
	N (15)	***%***	***N (15)***	***%***	***N (30)***	***%***
Patient	5	33	8	53	13	43
Bacteria	10	67	9	60	19	63
T.E	4	27	10	67	14	47
Effectiveness of antibiotic	15	100	15	100	30	100

It can be seen that most of the students thought about the bacteria and the antibiotic. The component from the molecular level (transposable element) of bacteria has been poorly represented and so was the status of the patient. The upward level thinking was observed as the effectiveness of antibiotic was related to organism level (bacteria) but was not linked to the molecular level (insertion sequence)

Question 2b: Similarly, overall only one tenth of the students provided complete answers (table 12. 5).

Table 12.5 Categorisation of answers of question 2b

	Category 4	Category 3	Category 2	Category 1	
Partly open Q	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	*fragmented*	*Less complete*	*complete*	
Q2b					
College 1	10 (48%)	4 (19%)	6 (29%)	1 (5%)	21 (100%)
College 2	5 (28%)	4 (22%)	6 (33%)	3 (17%)	18 (100%)
Combined	15 (38%)	8 (21%)	12 (31%)	4 (10%)	39 (100%)

Table 12.6 shows that ineffectiveness of the available antibiotic was mentioned by more than 90% of the students. However, only one half of the students looked beyond the given information stating the need of having another antibiotic. More than half of the students brought resistance gene into the linkage. Bacteria and the status of the patient have been poorly reported.

Table 12.6 Detailed analysis of question 2b

Components	**College number 1**		**College number 2**		**Combined**	
	N (15)	**%**	**N (15)**	**%**	**N (30)**	**%**
Patient	7	54	5	36	12	44
Bacteria	2	15	2	14	14	15
Resistance gene	6	46	10	71	16	59
Effectiveness of antibiotic	12	92	13	93	25	93
Another antibiotic	5	38	9	64	14	52

Questions 3a and 3b: In these questions, scaffolding was given by mentioning the direction of the answer expected from students. They were expected to link the given one piece of information to the components belonging to levels above and below it in 3a and to levels above in 3b.

(3) Explain the cause and effect of the following elements

(a) Presence of anthocyanin
(b) Unstable gene mutation

Question 3a: Most of the students' responses were noted to be fragmented (table 12. 7).

Table 12. 7 Categorisation of answers of question 3a

	Category 4	Category 3	Category 2	Category 1	
Partly open Q	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
Q3a	***Very fragmented***	***fragmented***	***Less complete***	***Complete***	
College 1	6 (30%)	8 (40%)	4 (20%)	2 (10%)	20 (100%)
College 2	2 (13%)	8 (50%)	3 (19%)	3 (19%)	16 (100%)
Combined	8 (22%)	16 (44%)	7 (19%)	5 (14%)	36 (100%)

The detailed analysis (table 12. 8) focused on the direction of thinking reflected from students' answer. A large number (54%) of answers reflected *upward level thinking* where students related the given information (presence of anthocyanin) to the level above, organism/organ level (speckled corn seed). In contrast, only a small fraction (7%) of students engaged in *downward level thinking*: linking the given information to the level below (molecular level). However, *yo-yoing* (upward level thinking + downward level thinking) was not demonstrated by a majority of students.

Table 12.8 Detailed analysis of question 3a

Components	**College number 1**		**College number 2**		**Combined**	
	N (14)	%	N (14)	%	N (28)	%
Downward Level Thinking	1	7	1	7	2	7
Upward Level Thinking	8	57	7	50	15	54
Yo-yoing (upward + downward)	5	36	6	43	11	39

Question 3b: Answers to question 3b showed the same trend as that of 3a where the 'complete answer' has not been found as the modal category (table 12. 9).

Table 12. 9 Categorisation of answers of question 3b

	Category 4	**Category 3**	**Category 2**	**Category 1**	
Partly open Q	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	***fragmented***	***Less complete***	***complete***	
Q3b					
College 1	6 (35%)	3 (18%)	6 (35%)	2 (12%)	17 (100%)
College 2	4 (27%)	9 (60%)	2 (13%)	0	15 (100%)
Combined	10(31%)	12 (38%)	8 (25%)	2 (6%)	32 (100%)

Table 12.10 shows that the impact of unstable mutation was related to the speckled seed (organ level) by a high proportion of the students (upwards level thinking). However, more than 85% of the students by-passed the organelle level in their explanations as they did not mention anthocyanin; almost all did not mention the chromoplast, nucleus (the components from the organelle level) and chromosome (molecular level). Students brought the minimal number of the elements in their explanation even which was enough to explain the phenomenon.

Table 12.10 Detailed analysis of question 3b

Components	**College number1**		**College number 2**		**Combined**	
	N(16)	**%**	**N(14)**	**%**	**N(30)**	**%**
Molecular level						
Chromosome	0	0	0	0	0	0
Gene C	11	69	11	79	22	73
AC	10	63	2	14	12	40
DS	10	63	9	64	19	63
Enzyme	10	63	5	36	15	50
Organelle level						
Chromoplast	0	0	0	0	0	0
Anthocyanin	4	25	1	7	5	17
Nucleus	0	0	0	0	0	0
Organ						
Speckled corn	14	88	10	71	24	80

Questions 4 and 5: In question 4 students were expected to pick up the related information and to explain the phenomenon; in question 5 they had to predict about the gene.

(4) Here are six items.
*Tick **three** that are directly related to each other.*

Gene *c* (mutant)	Gene W (wild)
Chromosome 9	Unstable mutation
Purple corn seed	RNA

What can you explain with the help of these three related elements? (One sentence)

(5) What happens to a gene responsible for pigment production in corn seed, when a transposable element jumps into it and stays there permanently?

Category 3 and 4 (fragmented) have been found to be the modal category for Q4 and Q5 respectively (table 12.11).

Table 12. 11 Categorisation of answers of question 4 and 5

	Category 4	**Category 3**	**Category 2**	**Category 1**	
	0-25%	26-50%	51-75%	76-100%	N
Pertly open questions	***Very fragmented***	***fragmented***	***Less complete***	***complete***	
Q4					
College 1	7 (30%)	11 (48%)	3 (13%)	2 (9%)	23 (100%)
College 2	4 (21%)	12 (63%)	2 (11%)	1 (5%)	19 (100%)
Combined	11 (26%)	23 (55%)	5 (12%)	3(7%)	42 (100%)
Q5					
College 1	13 (68%)	4 (21%)	2 (11%)	-	19 (100%)
College 2	7 (41%)	6 (35%)	2 (12%)	2 (12%)	17 (100%)
Combined	20 (56%)	10 (28)%	4 (11%)	2 (6%)	36 (100%)

Only a tiny fraction of students provided a complete answer. They did not communicate the linkages between the given components efficiently. Indeed, many of them did not go beyond the information given to explain the phenomenon on organism level.

12.4.3 Fully Open-ended Questions

Question 8 and 9 were fully open-ended questions.

Fully open ended questions

(8) Explain in detail why and how a corn seed becomes speckled?

(9) Draw a diagram or series of diagram to illustrate why a corn seed becomes speckled?

Students were given freedom to bring into their answers as much information as they wished. Their answers to these questions have been considered as the expressed representation of their mental models. These expressed models have been used to evaluate the extent of completeness while recognising that their answers will not be a perfect representation of the students' understanding about the phenomenon of speckled corn seed.

Question 8: Overall, the proportion of students' answers was almost evenly distributed in the categorisation spectrum (table 12.12).

Table 12.12 Categorisation of answers of question 8

	Category 4	**Category 3**	**Category 2**	**Category 1**	
Fully Open-ended Questions	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	***fragmented***	***Less complete***	***complete***	
Q8					
College 1	2 (12%)	3 (18%)	4 (24%)	8 (47%)	17 (100%)
College 2	7 (41%)	5 (29%)	4 (24%)	1 (6%)	17 (100%)
Combined	9 (26%)	8 (24%)	8 (24%)	9 (26%)	34 (100%)

Table 12.13 (next page) shows that, overall, only six components have been represented in their answers by more than 50% of the students. These six components (highlighted blue in the table) are the fundamental components in the explanation of the phenomenon. More than half of the students did not mention the corn seed in the explanation they provided. Perhaps it was too obvious to be mentioned explicitly. Gene, which is the unit of genetics, was highly represented while only a handful of the students paid attention to the gene size.

Table 12. 13 Detailed analysis of question 8

Components	**College number 1**		**College number 2**		**Combined colleges**	
	N (17)	**%**	**N (16)**	**%**	**N (33)**	**%**
Nucleus						
Chromosome	10	59	4	25	14	42
Short arm	6	35	3	19	9	27
Gene						
Gene c	15	88	11	69	26	79
Gene size	9	53	3	19	12	36
Gene activity	10	59	5	31	15	45
Unstable mutation	9	53	6	38	15	45
Repetition of Tran.	12	71	12	75	24	73
Transposable element						
TE	11	65	14	88	25	76
AC	15	88	4	25	19	58
DS	17	100	8	50	25	76
Enzyme	10	59	6	38	16	49
Chromoplast						
Chromoplast	8	47	3	19	11	33
Anthocyanin	11	65	8	50	19	58
Seed						
Purple	9	53	5	31	14	42
Yellow	9	53	6	38	15	45

Question 9: The answer to this question was in the form of a diagram which has also been considered as an expressed mental model of the students. Category 3 was found to be the modal category (table 12.14).

Table 12. 14 Categorisation of answers of question 9

	Category 4	**Category 3**	**Category 2**	**Category 1**	
Fully open-ended questions	(0-25%)	(26-50%)	(51-75%)	(76-100%)	N
	Very fragmented	***fragmented***	***Less complete***	***complete***	
Q9					
College 1	2 (17%)	5 (42%)	1 (8%)	4 (33%)	12 (100)
College 2	3 (21%)	5 (36%)	5 (36%)	1 (7%)	14 (100)
Combined	5 (19%)	10 (38%)	6 (23%)	5 (19%)	26 (100)

The drawings were also analysed in detail to see if students were able to use the systems-based model spontaneously. One half of the students followed the systems-based model. A large proportion of the students' answer reflected the hierarchical nature of the system. Different levels have been well represented by more than half of the students. However, the open nature of the system was poorly represented.

The quality of their expressed model varied. Structural components and processes (Chromosome, gene c, DS and process of transposition) have been represented in more than 70% of the answers. The most poorly represented components were enzyme, gene size, chromoplast and anthocyanin.

Table 12.15 Detailed analysis of question 9

Components	College number 1		College number 2		Combined colleges	
	N (10)	%	N (14)	%	N (24)	%
Levels (exp)	4	40	6	43	10	41
Organism	8	80	7	50	15	63
Organ	5	50	9	64	14	58
Organelle	6	60	9	64	15	63
Molecular	5	50	9	64	14	58
Hierarchical nature	8	80	8	57	16	67
Open nature	4	40	5	36	9	38
Followed model	6	60	7	50	13	54
Components						
Nucleus	6	60	6	43	12	50
Chromosome	8	80	9	64	17	71
Gene c	9	90	8	57	17	71
AC	10	100	5	36	15	63
DS	10	100	8	57	18	75
Enzyme	1	10	5	36	6	25
Gene size	6	60	2	14	8	33
Process Transposition	9	90	8	57	17	71
Chromoplast	3	30	4	29	7	29
Anthocyanin	3	30	4	29	7	29

Almost the same components which were highly represented in answer to question 8 also appeared in answer to question 9. However, chromosome appeared in question 9 while it was under-represented in the essay questions. Abstract entities (enzyme and anthocyanin), although not very well presented in both the questions, however, have high representation in the essay questions. From the organelle level, chromoplast has been missed out equally in drawing as well as essay questions.

Although comparison between the two colleges was not an intention of the study, because of the small sample size and also because it was an exploratory study, there were some obvious differences in students' answers from the two colleges. A brief account of the comparison based on very obvious differences is presented.

12.4.4 Comparison of the Two Colleges

The small number of participants in the two colleges makes statistical comparisons more or less impossible. However, the data in table 12.16 does suggest some possible differences in the way the students from the two colleges performed.

Table 12.16 Comparison of students' performance from two colleges

College	*Q1*	*Q2a*	*Q2b*	*Q3a*	*Q3b*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Q9*	*Total*
College 1	ND			ND	X	ND		X	X	X	X	5
College 2	ND	X	X	ND		ND	X					3

Legend: **ND**: no difference **X**: 'outperformed'

Students from college 2 seem to deal with the information dense scenario better than students from college 1 which means that their answers to Q2a and Q2b were showing better linkage than the other group (table 12.3 and 12.5). Organelle level was bypassed in 3b by both the colleges. They paid attention to the components which were directly involved. Answers to question 8 and 9 were different in two colleges. The high percentage of students who produced complete answers was found to be higher in favour of students from college 1. Overall students from college 1 performed better than college 2.

12.5 Outcome of 'Approach Finding Survey'

Students' preference to arrange the given information in a logical order was explored (*approach finding survey*). The elements in the task involved part-whole structure (Markman & Callanan, 1984) of the collection which means that a system was disassembled into its components and students were asked to arrange the components in any logical order.

The analysis focused on students' priority to organise the given elements in a logical fashion. If their logical arrangement started with the bigger components in a descending order then the approach was called *top down approach* (TODA). If starting with the smaller component in an ascending order, it was named as *bottom up approach* (BUPA).

Students from college 1 and college 2 were noted having PUBA and TODA respectively (table 12.17). Chi-square test was used [^{2} =7.89 (df =1), $p < 0.01$]. Thus the students from two colleges were found significantly different in their approach to part whole structure.

Table 12. 17 Students' approach to part-whole structure of the system

	Top down approach		*Bottom up approach*		
	N	%	N	%	N
College 1	11	28	28	72	39
College 2	17	62	10	37	27
Combined	28	42	38	58	66

12.6 Discussion

There were three objectives of the analysis mentioned earlier in this chapter:

(1) To explore the quality of students answers.
(2) To explore what test item students were good at answering?
(3) To explore what do students' answers reveal about their understanding?

Each is now considered in turn.

(1) Quality of students' answers.

It has been observed that most of the answers tended to be fragmented. Nevertheless there were some exceptions as well. Although it was beyond the scope of this study to talk to the students about the answers they produced, there could be a number of explanations for the incompleteness of their answers.

For instance, perhaps the marking scheme used was too rigid and strict. It expected the students to bring all the relevant pieces of information into their explanation and this was not widely observed from their answers. Of course, a phenomenon can be explained with a minimal number of components by avoiding complexity and using a minimum number of interrelated variables in the explanation. Perhaps, the written test did not give the students enough opportunity to show the range of their understandings.

Students are not usually penalised for missing out the indirectly relevant elements in an explanation and this may have influenced their answering. Therefore, it is possible that students' selection criterion for bringing the elements into their explanation was being operated in line with their traditional assessment experience. In addition to this, the researcher did not indicate what types of answers were expected from them.

(2) Type of questions students were good at answering

It has been noted that the quality of answers varied across three types of questions: closed, partly and fully open-ended questions. For each question, the percentage of students producing complete answers (both categories) were combined together (table 12.18).

Table 12.18 Comparisons of students' performance over different types of questions

	Closed Questions			**Partly Open-ended Questions**						**Open Questions**	
	Q1	***Q6***	***Q7***	***Q2a***	***Q2b***	***Q3a***	***Q3b***	***Q4***	***Q5***	***Q8***	***Q9***
%	94%	62%	58%	30%	41%	33%	31%	19%	17%	42%	50%

The percentage of complete answers has been observed in the following order:

Closed question > Fully open ended > Partly open ended question.

There seems to be a link between the type of questions asked and the category of the answers produced which means that the formulation of test items has a contribution in eliciting the information.

The closed questions drew a boundary for students. Such questions presented information before posing the question to be answered and a skeleton of the answer was also given. Perhaps setting the boundary and signalling the information needed may have reduced the cognitive load allowing students to think through only about the specific information step by step. In a sense, this imposed constraint acted as a scaffolding for students. However, it may simply be that students were used to answer such type of questions.

It is more difficult to interpret the observation that students did better in the fully open questions. Perhaps the freedom offered here allowed them to select their own information at their own pace, thus giving a more complete answer. In partly open ended questions the information was given and students had to connect these fragments of information to present complete answer. It may be that in case of imposed limit when there was no scaffolding for eliciting answer, they struggled with the information dense question and could not decide what to bring into the explanation and thus many of them failed to link all the given information. Perhaps the amount of information (in some cases from different levels of organisation of two organisms, bacteria and man) in the absence of scaffolding overwhelmed the students by putting a cognitive pressure on them.

(3) Students' understanding revealed in the answers

It is always difficult to make accurate deductions about what student actually understand by looking at examination questions. Nonetheless, the style of questions used was such that some conclusions could be drawn.

Firstly, looking at 2a, 3a & 3b, it has been observed that most of the students were inclined towards *upward level thinking* (making links to the level above that of the given information). This finding is consistent with what Leach et al. (1996) observed in ecology. They reported that, on the hierarchy of trophic levels, students tended to move upward. Similarly, Hogan (2000) and Hogan & Weathers (2003) also reported students' tendency to move upward from the bottom of the food web. Very recently, Reiser and Duncan (2007) also reported a same kind of observation that the students mapped the information (genetics) to the higher levels of organisation and called such explanations 'tautological' because they lacked the explanation about the mechanism from the lower levels.

Secondly, ‘yo-yoing’ (upwards + downwards level thinking) was not widely observed in students’ answers. Although, students expressed their opinion that the systems-based material was helpful in making them think in levels (yo-yoing) yet it was not observed in practice. This is consistent with Reiser and Duncan (2007) and

Hogan's (2000) findings in genetics and ecology. Believing, understanding and practicing do not always match consistently. It was either they believed that they could do yo-yoing and then failed to practice it; they deliberately did not get involved in it or they still did not grasp the idea of thinking in levels

Thirdly, however, whenever they did yo-yoing they missed the intermediate links and components. Most of them by-passed the organelle level (chromoplast, anthocyanin, nucleus) in their answer. Of course, the absence of this did not necessarily imply total ignorance of the link. Marbach-Ad and Stavy (2000) have also reported that, when 12th graders studying genetics were asked to respond to questions, they did not make bridge between levels as they skipped the intermediate mechanisms involved in making links to explain the phenomenon from different levels of biological organisation. Similarly Magntorn and Hellden (2007) reported a younger sample of students studying ecology making single step relations without any mediating description of a sequence of causally linked events and relations. Reiser and Duncan (2007) also reported students producing 'truncated explanation' where they mapped information inappropriately by linking the gene directly to the observable phenomenon while missing out the mediating mechanism and components from the other levels.

Finally, answers to fully open questions indicated some understanding of students' preferences to explain the phenomenon. The components which were directly related to the phenomenon, for example gene c, DS, AC and process of transposition were almost equally represented in both the open questions (Q8 & Q9). However, there are some components which have been noted having more representation in written answer than in the drawing and vice versa (table12. 19)

Table 12.19 shows that abstract entities (enzyme, anthocyhain) occurred in writing essay and structural components and processes were mentioned in drawing. Perhaps structural components and processes were easy to imagine and draw than the chemical substances. Being a structural component, chromoplast has been ignored in both the answers which mean that students concentrated on the hub of the activity (nucleus) and bypassed the chromoplast as it has been evident from other answers as well. As there is not much reference to what was happening at the organelle (chromoplast); perhaps students presumed that any biological phenomenon that has genetic origin does not necessarily need other components from the other levels for explanation.

Table 12.19 Representation of components in two questions

Components	**Q8**	**Q9**
Enzyme	49%	25%
Gene size	36%	33%
Chromosome	42%	71%
Chromoplast	33%	29%
Anthocyanin	58%	29%

More than half of the students followed the systems model in their drawing with fairly good representation of the levels in a hierarchical fashion. However, the open nature of the system was not very well observed.

Students from college 1 reflected bottom up approach to part-whole structure and they also performed better than the students from college 2. Although due to the small sample size, statistical tests could not be performed to show if there was an association between the performance of the students and their approach. However, Jacobson and Wilensky (2006) have reported an association between the approach and performance of the students. They associated bottom up approach to the greater understanding of the complex system. The present study is consistent with this. Firstly, students from college 1 had bottom up approach, secondly, they performed well on the test and thirdly the merit or admission qualification of college 1 have been found higher than the college 2.

To sum up, the analysis illustrated that students answers were fragmented; they performed better on closed and fully open questions than partly open questions; most of them were engaged in upward level thinking; yo-yoing was not widely observed, they by-passed the intermediate level (organelle level). Performance of college 1 has been observed comparatively better than college 2; students have been found different in their approach to part whole structure of the disassembled system.

12.7 Critique of 'Complexity Indicator' Scheme

The scheme which was created in this study for identifying the quality of students' understanding does not provide a sophisticated measure of complexity. However, even in its crude form, it seems useful for identifying different aspects of students' understanding such as

(a) *The completeness of their answers*, the amount of information available from all the levels and components required for a complete, complex answer;
(b) *Tendency of their thinking* to link information: upward level thinking, downward level thinking and yo-yoing (sections12.4.2);
(c) *Mapping the patterns of* missing information and levels of biological organisation;
(d) *Identifying the pattern of performance* across different types of questions (Section 12.6);
(e) *Identifying the differences in the representation of components* between drawing based and text-based questions (section12.4.3).

Certain weaknesses in the scheme should be noted. The scheme does not measure the strength of links between components and levels of biological organisation. Students were not informed of the criterion to be used to evaluate their answers and therefore may have decided not to include some of information as they might have considered it unnecessary.

CHAPTER THIRTEEN

Research Questions and the Way Forward

13.1 Introduction

This final chapter brings together the findings of this research project. The aim is to highlight the contributions of the study to the understanding of the importance of using systems-thinking in biology education as a teaching and learning tool. The chapter includes an overview of the current study, offering a broad outline of the changing research and educational landscape in biology. It presents the understandings about the nature of systems-thinking in general and in the context of education particularly. Possible ways of incorporating systems-thinking to enrich the existing biology teaching and learning (answer to the first half of research question) are discussed. It highlights students' opinion regarding the impact of systems-based educational material on their learning process (answer to the second half of research question) with suggestions about the pedagogical implications for biology education from systems perspective. Limitations of the current study are also presented and the chapter concludes with recommendations for future research.

13.2 Overview of the Thesis

The first aim of this study was to explore the ways of using the notion of systems-thinking in biology education to enrich the teaching and learning process. The emphasis on relational understanding was seen as a potential catalyst in enhancing students' coherent understanding by presenting the information in a unified, systems manner. Secondly, the study aimed at exploring student's opinion about the systems-based educational material.

The paradigm shift in biology research from reductionism to systems view has been noted and views about systems biology explored. Difficulties associated with the learning of genetics are summarised and there is an outline of various models of learning with the educational insights they provide. After discussion of research design, there is a description of three phases of enquiry. This chapter seeks to bring together the major findings and the answers to the research questions while implications, limitations and need for the further research are presented.

13.3 Shifting Ground in Biology Research

Chapter two and three and also the findings from the interviews conducted with biology researchers (section 8.5) have highlighted the shifting paradigm and hence changing research practice. 'Systems biology' is the label given to a new approach in biology research but this involves an old core idea of coherence and integration with the acquired and the incoming information, an integration within the discipline and an integration of technology and experts. Systems biology has not discarded the reductionist approach. This is still appreciated and practised but the new approach has brought a balance between analysing and synthesising. However, this integration appears to be a difficult and challenging transition as it puts many demands on future biologists to be multidisciplinary as well as considerable pressure on the educational system. Designing educational courses regarding systems biology has been reported as challenging and demanding.

13.4 The Educational Landscape in Biology

The study has offered considerable insight into views of both teachers (lecturers) and students about biology educational practice at school and university levels and also a spectrum of students' understanding and attitude towards studying biology.

Genetics has been noted as a difficult area for students to learn (section 8.7, section 9.4). A number of reasons have been associated with this difficulty and can be traced back to all three elements of educational importance such as the nature of discipline, the teaching practice and the learners' inherent problems or limitations:

- *Much technical terminology and information;*
- *Involvement of chemistry and mathematics;*
- *Microscopic nature of genetics phenomenon;*
- *Problems associated with information integration from different levels;*
- *Lack of logical reasoning;*
- *Misconceptions about genetic concepts;*
- *Lack of organising principles;*
- *The sheer amount of information may generate information overload.*

Lecturers have also some problems associated with the teaching of biology:

- *Too much information available and hard to decide what to teach;*
- *Dynamic nature of the subject;*
- *Keeping pace with the incoming information;*
- *Large and heterogeneous classes of students;*
- *Evoking the zeal and motivating the students;*
- *Too much technical vocabulary;*
- *Teaching with systems perspective (potential future problem);*
- *Complexity of the subject.*

Based on students' understanding and their attitudes towards studying biology, biology lecturers have developed some views about the teaching practice at school level. Lecturers believed the lack of coherent understanding could be traced back to school teaching and assessment, believing that students are not empowered to take responsibility for their own learning as they are heavily dependent on their teachers. They bring the same attitude to the university where lecturers cannot offer the same support and direction and students find this difficult.

Educational practice at the first two years of university has been considered fragmented and there was not much deliberate attention paid on the integration of information. However, it was argued that this fragmented approach was a necessity because of the huge classes and also because the first two years laid the foundation for future learning. However, teaching and assessment in the final two years allowed greater integration of the different course material they are taught. They also had become more enthusiastic and interested about their learning. It was noted that postgraduate students have a good sense of connectedness and it was attributed to the teaching practice at the undergraduate level. This transition on the spectrum of understanding (from fragmentation to integration) and attitude (from lack of empowerment to being enthusiastic) appears to be a result of a number of factors such as maturity, mental development, experience, change in teaching strategies and assessment methods. In considering the views of university biology teachers, it is apparent that the same pattern of growth in integration of understanding will occur in many other disciplines and is not unique to biology.

13.5 Nature of Systems-thinking

While no concise universally agreed upon definition was found, different views about systems-thinking in the literature and with the interviewees were summarised. Systems-thinking can be conceived as a mental framework for thinking, doing and acting taking into account the relational recognition. Systems-thinking has been presented as a mind set (a way of thinking) or a continuum of activities. There appear to be two levels of thought. It appears that those who regard systems-thinking as a process, mental framework or way of thinking (soft view of systems-thinking) see it as a general ability. However, for those who hold a hard view of systems-thinking (a set of activities like mathematical and computer modelling), to them it is a high order thinking skill.

In biology education, systems-thinking has been recognised as awareness about the nature and structure of biological systems, and an ability and willingness to look for the links and connections to develop understanding. The teacher is seen as a source and model of systems-thinking for the students so s/he is required to bring and incorporate systems-thinking into every aspect of biology education.

It is recognised that systems-thinking is a complicated way of thinking which is mentally taxing. Extra effort and energy and extra attention is needed. This probably explains the lack of such thinking in general. People find it difficult to face a complex and information-rich system. Thus, in education, systems-thinking will be an educational challenge and it will be difficult to equip students with systems-thinking skills although these skills have been recognised as an essential part of literacy. It has been suggested that a deliberate effort is needed from other disciplines as well for making systems-thinking as a habitual pattern of thinking.

13.6 Systems-thinking in Action

This section provides answer to the first half of the research question and to achieve the first objective of this research study. The aim of the research was

- *To explore the way to use systems-thinking in developing systems-based educational material in biology*

Unfortunately, the definition of systems-thinking did not provide much indication of how to use systems-thinking as a teaching and learning tool. Therefore, the following procedure was adopted to incorporate the abstract concept of systems-thinking into concrete educational material. For this purpose following steps were taken:

Firstly, specific concepts of systems-thinking were selected and these were made explicit for the students. The structure and nature of biological systems was chosen, the very basic and fundamental aspect for studying biological systems. It included LOBO (levels of biological organisation) and open and nested nature of the system (Section 9.2.1). The intention behind this was to emphasise the linking and connecting different pieces of information from different levels and within levels. The ultimate goal was meaningful and coherent learning.

Secondly, the definition of *'systems-thinking as a teaching and learning tool'* was operationalised. This involved:

> *Systems-thinking as an educational (teaching and learning) tool is making the learners aware about the whole (organisational structure of the whole in terms of levels of biological organisation), the parts and the links between them; firstly, by organising the biology education, keeping in view the levels of biological organisation in such a way which makes the learner aware about the links between components and levels; secondly by providing a framework and an opportunity for the learner to think in terms of levels of biological organisation in context (of the phenomena of transposition).*

Thirdly, the elements of this operationalised definition were converted into specific objectives:

- To present the ***teaching and learning material*** (the phenomena of transposition) which identifies the levels of biological organisation, and explain the connectedness between components and the levels involved.
- To provide an ***explicit framework*** to make learners perceive and visualise the *levels of biological organisation,* the links between levels and their components.
- To provide learners with ***opportunity*** to practice *systems-thinking*

Finally, these objectives were translated into reading material, models and questions.

Although, modern technology is a powerful way for introducing and making people think in systems way, it was decided to use established traditional practices in this study as a means enriching understanding by aiming at coherent and meaningful learning.

There are very many reasons for genetics being difficult to learn. However, the present study especially took into account the nature of the message: complex, multilevel, microscopic and abstract nature of the systems. The notion of systems-thinking as an educational tool has been successful in dealing with these issues in three ways: by making the levels of biological organisation and nature of the system explicit to the students and by ascending and descending on the levels of biological organisation through the reading material and by providing them a framework in the form of a model and also allowing them to be engaged in linking different levels (vertical) and components on the same level (horizontal). However, it has also reduced the cognitive load and presentational issues of the information by presenting the material from a systems perspective.

The material was developed with three features:

- *Systems-based reading material, using a narrative style and personifying the biological elements;*
- *A systems-based model;*
- *Systems-based questions.*

However, their implications may be dependent upon the need, educational level of the students and time available. But for sustained educational effort it is recommended to incorporate the element of systems-thinking in all areas of biology education. The model provides a spatial frame work for thinking and imaginations. Nonetheless, the current model is simple and it can be modified to be more complex for higher levels of education and it can be made even simpler (reducing the levels of biological organisation according to the educational levels of the students) for the younger learners. Perhaps, the systems-based model and the questions are applicable for all levels of biology education. However, the narrative style, although quite interesting and engaging, is perhaps more suitable for the younger learners in biology education. However, it is recommended to incorporate the element of systems-thinking in all areas of education

Although the reading material, the model and the questions may all be important, the role of the teacher is of utmost importance. Not only is the teacher a source of information and a catalyst to enthuse the learners but the teacher is a model of thinking patterns. Hence, from the platform of this research study, it is recommended that before bringing the concept of systems-thinking to the biology class, let us turn to a level above in the hierarchy of educational systems: towards the trainee teachers and enthuse them to carry a torch of systems-thinking in their class. The teacher needs to be committed to this paradigm of thought and the initial teacher education as well as continuing professional development is important. Therefore it is recommended to introduce the major tenets of systems theories to teacher training courses and make it a regular part of the teacher training.

Another area of difficulty lies in assessment. If, for various reasons, this tends to reward the recall and recognition of knowledge and does not reward the ability to bring knowledge together in a meaningful and coherent way, then there is little encouragement for either teachers or learners to engage with systems-thinking.

In the light of the principles working behind the development of systems-based material (chapter 9), information gleaned through interviews with biology sductaionists (section 10.5) and insights gained through students' opinion with systems-based education material (chapter 9, 11), systems-based pedagogical principles for biology can be presented:

1. *Keep in view the nature of the systems (nested, open and dynamic nature);*
2. *Keep in view the structure of the system (levels of biological organisation, interrelation);*
3. *Teach without slicing biological themes by biological levels;*
4. *Teach keeping in view the complexity of the system;*
5. *Engage the learners in yo-yoing in all educational aspects (reading, questioning);*
6. *Start your explanation with the concrete level for younger learners and always relate the information from lower levels to the organism level I other cases;*
7. *Present the information in an organised way taking into account levels of biological organisation, as it provides a spatial frame of references for organising thoughts and arranging knowledge;*
8. *Impose systems-based questions which would allow, force and make them to*
    - *Look for dynamic interaction if it is needed,*
    - *Seek for relationship between components of different levels,*
    - *Seek relationship between the components of the same level.*
    - *Predict and retrospect about the phenomenon from different levels;*
9. *Teach for developing, enhancing and stimulating biological thinking (systems-thinking);*
10. *Assess to reflect systems-thinking in that there should be reward for evidence of thinking in this way.*

This set of principles offers a basis for the formulation of systems-based pedagogical principles for biology. Overall, the answer to the first half of the research question is the *development of the procedure adopted* for designing the material from systems perspective, *the material developed* and the *formulation of systems-based pedagogical principles* for biology.

13.7 Impact of System Based Educational Material

This section provides an answer to the second half of the research question and achieving the second objective of the research project.

- *To investigate how students deal with the systems-based teaching and learning experience.*

The intention here was to explore the overall impact of systems-based material on students' attitudes. The students in the first case study expressed a positive opinion but the students from second case were found to be somewhat overwhelmed with their educational experience with the systems-based material. It was a thought-changing episode for them.

Some broad conclusions can be summarised based on the evidence gathered:

- Systems-based educational material has the potential to enhance students' understanding by fortifying their learning process.
- The evidence suggests that the whole experience with systems-based educational material has had an impact on student thinking. However, there was some uncertainty about the extent to which they had already started to think this way, this uncertainty being larger in the first case study. Of course, change and development in thinking patterns does not take place overnight. However, perhaps the two additional elements in Pakistan study (the introductory lecture about systems-thinking and the delivery of material through lecture from systems perspective with the involvement of teacher in asking the questions through yo-yoing) made a difference and made the transition a bit quicker for the students. However, this needs further study.
- The evidence suggests that material is helpful in understanding the multi-levelled nature of biological systems and links between them. However, the yo-yoing was not observed in students' answers and this opens further avenues for probing the reasons why this is so.
- Systems-based educational material has made it easier to understand the phenomenon of transposition and the evidence suggests that this approach can be helpful in understanding genetics. However, the extent of its

usefulness could not be determined at this stage because there is no evidence from the current available data to deduce how far students went in their development and application of systems-thinking. Nevertheless, there is a strong optimism about its usefulness, but through sustained educational efforts: consistent and intentional inclusion and use of systems-based approach in the class.

- There was an indication that students wish to have more educational material of this nature, especially the worksheets, which suggests that students found them useful.

Apart from this, students' opinion was also explored to find out in what ways the three elements of the educational material (systems-based text, model and worksheet) were helpful in their process of learning the phenomenon of transposition. These are presented below.

First of all the reading material has been found successful in

- *Focusing their attention;*
- *Engaging them emotionally;*
- *Evoking and rousing their imagination;*
- *Yo-yoing;*
- *Handling information, e.g. retention of information, integration of information, organisation of information;*
- *Reducing the cognitive or working memory load.*

The information was provided in an integrated and organised way, thus encouraging the students to link ideas to each other and to previous knowledge. Perhaps this reduced the cognitive load on their working memory and, thus, more could be retained in the sense of meaningful learning. However, the extent of retention needs further empirical evidence.

Secondly, it was encouraging to note that all the elements or features of the systems-based model which were intended to be noticed by the students caught their attention. Hence, a systems-based model has been successful in incorporating, carrying, conveying and reflecting the elements which was its purpose. However, there were two broader realisations expressed by the students. They realised that a systems-based model offered a broad presentation of biology lesson and recognised the necessity of a systems-based model as a main requirement for understanding biology. The usefulness of the model was found as follows:

- *Helpful in internalising the concept of LOBO (levels of biological organisation);*
- *Offered a structured spatial framework firstly, for thinking and imagination; secondly, for presentation and arrangement of information;*
- *Enabled them to see the big coherent picture of the phenomenon presented in the reading material;*
- *Enabled them to develop their mental model about the phenomenon.*

However, there was a limitation pointed out by the students about the systems-based model: it was very simple in terms of offering information. It is a relevant criticism but the purpose of the model was very basic and fundamental. This was to present the nature and structure of the biological system, not the complexity or dynamic nature of the system. However, it is worth noting for further research.

Thirdly, the work sheets were well received by the students. The systems-based questions have been proved to be effective scaffolding in their learning process:

- *Stimulated and assisted their thinking, forced and evoked their imagination to visualise, think and link the LOBO hence enabled them to think broadly in biology;*
- *Enabled them to think analytically and also to look for connection hence to see the whole picture of the phenomenon;*
- *Focused their attention and engaged them;*
- *Changed their habit of reading*

However, in spite of these positive indications students found it hard dealing with the systems-based questions and producing their answers as well. Nevertheless, the problem was not associated with the ambiguity of the questions. The reasons expressed are following

- *Lack of experience with such questions and no mental readiness for the type of thinking these questions required;*
- *Questions required deep thinking;*
- *Too much information in the questions.*

The last point reflects the cognitive load. However, the information was accessible to their vision all the time and the questions on the worksheet acted as an extension of their working memory. Nevertheless, they still had to do the mentally taxing task in linking the information and effort which perhaps was found hard by them. While every effort was made to reduce the cognitive load, it was known that systems-thinking would be demanding in terms of time, energy and effort. Perhaps students brought their effort and energy but time was not enough for processing the information. Perhaps the time demand would be inevitable and later on when they would develop and adopt it as a way of thinking, they would also learn to develop mental strategies for themselves.

Even in writing the answer, they were not required to look for the facts but for links and connections and they found it quite demanding. Writing answers was hard for them because they were more used to reproducing memorised information. What was required here was a very different skill as they were being asked to consider all the information in seeking a more holistic picture leading to an answer. However, this difficulty was an intentional objective to make students see the links and the bigger picture of the phenomenon. Similarly, they mentioned that without the sound conceptual understanding they could not answer the question which was a positive step towards discouraging the factual recall.

The study has been found successful in exploring and finding the ways to use systems-thinking as a teaching and learning tool. It also had a positive impact on students' understanding and thinking. All the three systems-based educational elements (reading material, worksheet and models) have been found successful in helping students in a number of ways to enhance their process of learning. However, further empirical evidence is needed to see the extent to which learning has genuinely been enhanced.

13.8 Other Conclusions

Some other conclusions were also drawn from this current study relating to the students' approach to part whole structure (chapter 9, 12) and to working memory capacity (chapter 9). The detailed analysis of students' answers (chapter 12) throws light on students understanding and their thinking. It revealed that most of the answers provided by the students were of fragmented nature (less than 50% correct information). They performed better on the closed and fully open ended questions than the partly open ended question (section 12.6). Most of the students were found engaged in upward level thinking where they were inclined to link the given information to the level above (more familiar or obvious levels of biological organisation). In spite of their belief that the systems-based educational material had helped them in internalising levels of biological organisation, made them think in levels and to link levels of biological organisation, many of them were not found being engaged in yo-yoing as they produced 'truncated' answers by-passing some levels or information from these levels.

13.9 Limitations of the Study

A large amount of data was obtained and the new materials were found to be accepted with considerable enthusiasm. Nonetheless, the study did not afford an opportunity to explore if the actual learning (seen in terms of understanding) had been enhanced. Of course, traditional examinations would probably not offer the evidence and the assessment used in the study, while offering encouragement, did not provide clear unequivocal evidence of improved performance.

The samples for most of the study were good but the final study in Pakistan involved only women and the sample was inevitably small. Overall, the findings of the study need to be replicated with larger more representative samples over a wider range of the curriculum.

Nonetheless, despite the limitations of an exploratory study, the outcomes are encouraging in that there does seem to be scope to develop teaching more in line with systems-thinking and the students are positive and see this as helpful.

13.10 Significant Contribution of the Current Study

Overall this study has made significant contribution in understanding the use of systems-thinking as a teaching and learning tool for biology education, and also to the research in the field of biology education involving the notion of systems-thinking. The contribution of the current study is summarised below.

- *A procedure for using systems-thinking as an educational tool* was developed (Section 13.6) which guided the development of systems-based educational material for this study and can be employed as a guide for the development of further material or can act as a template.
- The study has developed systems-based teaching and learning units in the context of the phenomenon of transposition. The content of the units included *systems-based reading material*, *systems-based model* and *systems-based work sheets*. This educational material does offer a template for the development of further systems-based educational material for the other topics in genetics for different educational levels.
- This study also contributed in formulating, explicitly, the *pedagogical insights derived from systems theories* (Section 10.5.2) which could be employed by biology educationists for fortifying the existing pedagogical principles derived from the already established learning models.
- Formulation of *systems-based pedagogic principles* for biology education is another contribution of this study (section 13.6).
- Although open to further improvement and enrichment, a tool named the *'complexity indicator'* was created for a *detailed systems-based analysis of students' answers.* The purpose was to identify the complexity of students' answers by exploring different aspects of their understanding (chapter12). Similarly an approach finding (BUPA and TODA) test in the domain of biology and life in general was developed.

- The study also contributed in filling the gap for the dearth of research studies regarding systems-thinking and biology education especially at university level. In addition it has also opened up further avenues for research in this field.

13.11 Future research

This exploratory study has suggested some lines for further future research.

- It is needed to replicate the study to find out the effectiveness of systems-based educational material with a larger and mixed gender sample.

- It is required to conduct a controlled experimental research study to find out the extent to which systems-based educational material actually enhances students' understanding, impacts their thinking and also to what extent students can apply systems-thinking in other topics in genetics (or elsewhere) after their experience with the systems-based material.

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Appendix A

Reading Materials

(Scotland and Pakistan)

Unit No.1: Nature's Casanova

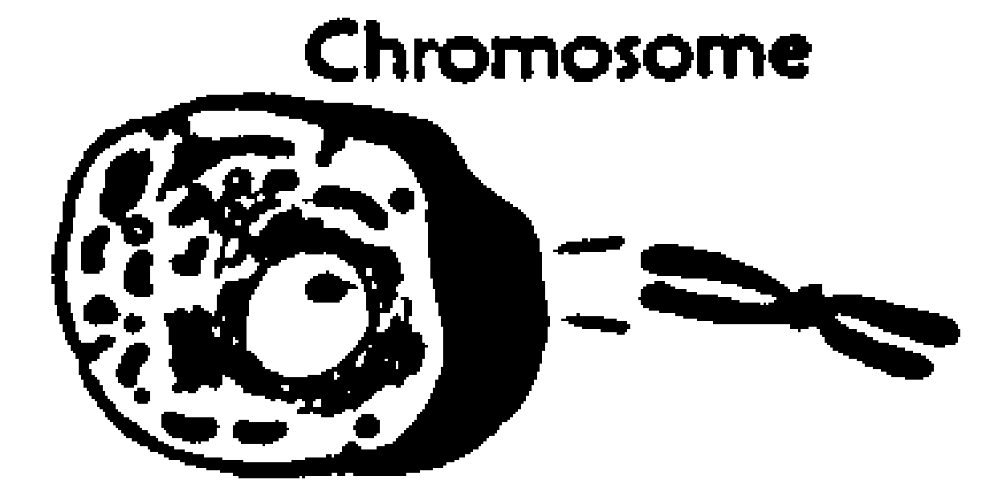
Transposable Element

(Jumping gene)

There are many levels in the biological world and numerous links between these levels. This booklet looks at the phenomena of **transposition** from many levels and tries to connect these for you.

A Guest from Faraway

Transposable Element



The biological world ranges from the microscopic to the macroscopic levels. All organisms can be seen as consisting of different levels of organisation (organs, cells, chromosomes (DNA), gene and molecular level). The DNA and gene level make up the genome, which is the total genetic material of the organism. Each gene (sequence of DNA) has a specific function and a specific location on a chromosome.

However, there are segments of DNA that do not code for anything. They are therefore not genes in the real sense. Junk DNA is a collective term for the portions of the DNA sequence for which no function has been identified. Certain DNA segments do not have a fixed place, are mobile and jumping around in the genome. These are called transposable elements, jumping genes, and the phenomenon is called transposition.

Imagine a transposable element from a microscopic level (gene level) is speaking to you. On the next page is an interview with a transposable element.

Let's read it.

An Interview with Michael Jordan
A Transposable Element

Hello.

Before introducing myself, I would like to give you a little of my history.

Thomas Morgan first described genes as beads threaded on a length of a chromosome, each with a fixed position. However, in the 1950s, Barbara McClintock showed that there were certain genes, which can jump from one place to another. These genes came to be known as transposable elements.

Since then I have been given different names. My favourite is Jordan gene, after the basketball player, Michael Jordan. I do not like some names: BBC science news called me 'Nature's Casanova'. However, I like being called 'sleeping beauty'. I'll tell you why in a moment.

Anyway, I'm mobile in the sense that I can move and insert myself or copies of myself throughout the genome. I do not have a specific address because of my restless nature. I move around while all the real genes have a specific permanent address.

Although I was first discovered in corn but you can also find me in many other organisms (fruit flies, human beings, pea seeds, bacteria etc). In fact the genomes of the most organisms include multiple copies of many transposable elements. 50% of human genome consists of transposable elements most of which have lost the ability to move. Part of the reason why the human genome is so large yet only contains 32,000 genes is that it includes a high proportion of transposable elements. Now let me explain why I'm called sleeping beauty.

In a 1997 study, University of Minnesota researchers took non-functioning jumping genes from a fish and made the genes jump again. This research had reactivated the jumping genes from millions of years of evolutionary sleep; hence, they named it Sleeping Beauty.

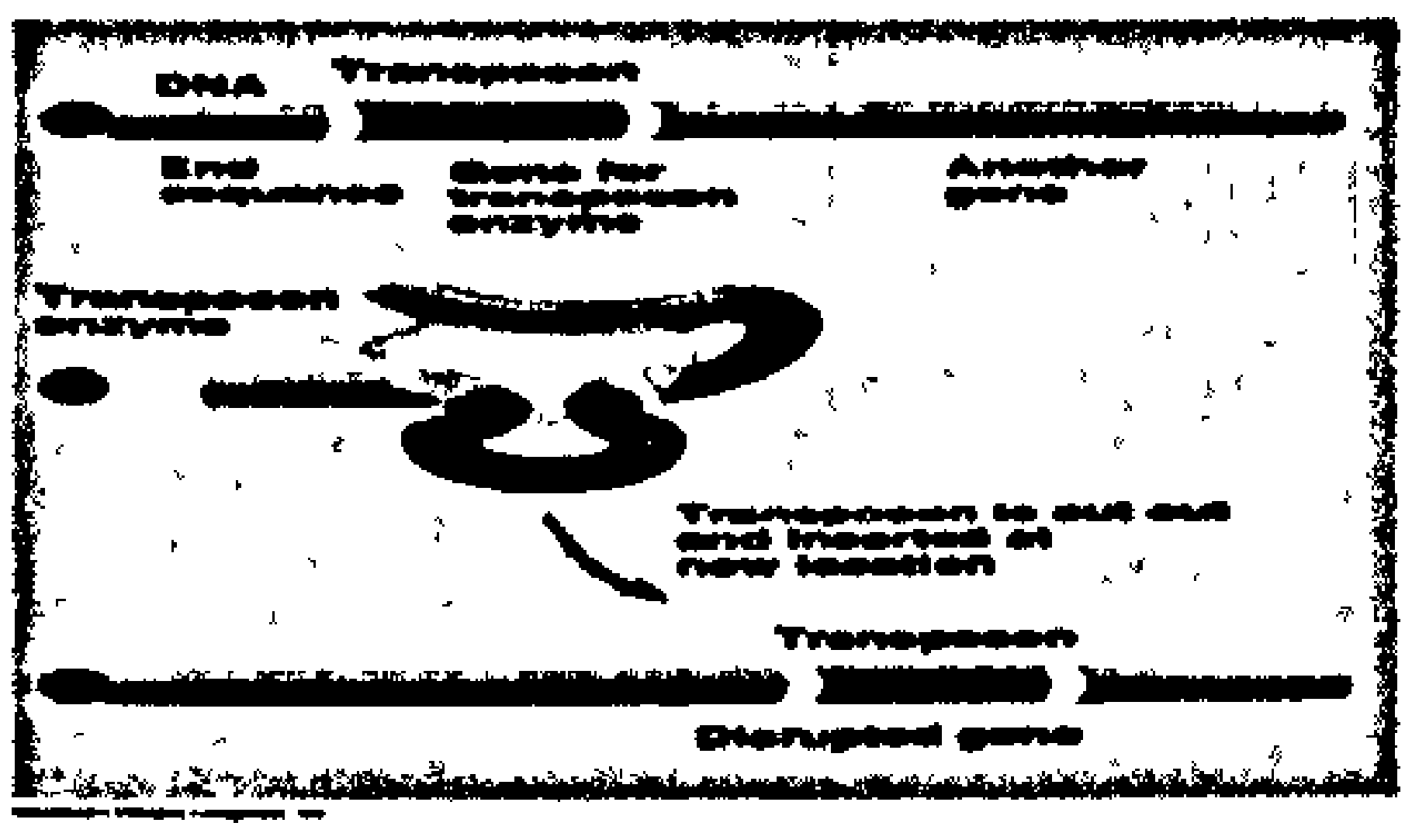
Well, today, the transposable elements found in bacteria will talk to you. On the basis of the complexity of the structure, there are different types of transposable elements found in bacteria. Let them introduce themselves.

Insertion Sequence

I'm a transposable element known as an Insertion sequence (IS). I am known for my simplicity. I am often called 'selfish DNA' because I use my bacterial host to replicate myself while providing nothing useful in return. My body is composed of two parts. Firstly, I have a main body and secondly I have terminal repeats. My main body consists of many DNA sequences but has only one gene. It codes for a protein called transposase that is needed for transposition because without this chemical I cannot jump. The second part is two terminals repeats surrounding the central body. They have special DNA sequences called inverted repeats.

I can move anywhere in the genome. If I get inserted into the coding region (Exon) of the gene for a particular trait then I can render a gene inactive. But if I land on a non-coding region (Intron) then I do not affect gene activity.

Fig1: Figure showing transposon, transposase (enzyme) and a disruptive non-functional gene.



Transposon

I'm another transposable element called a transposon (fig.1) and normally I am found in bacteria. My structural components, central body and terminal repeats, are similar to those of the Insertion sequence. However, apart from carrying a gene coding for an enzyme transposase, my central body also contains one or more other genes. Often these genes are responsible for antibiotic resistance. These genes move with the transposons from one bacterium to another. In this way I'm very useful for my host because I do not only selfishly insert myself into the genome of my host but also carry something valuable for the survival of my host. For example, if I'm carrying a gene for resistance to tetracycline, an antibiotic, and jump into the genome of another bacterium, then it will become resistant to tetracycline and the antibiotic will not kill it.

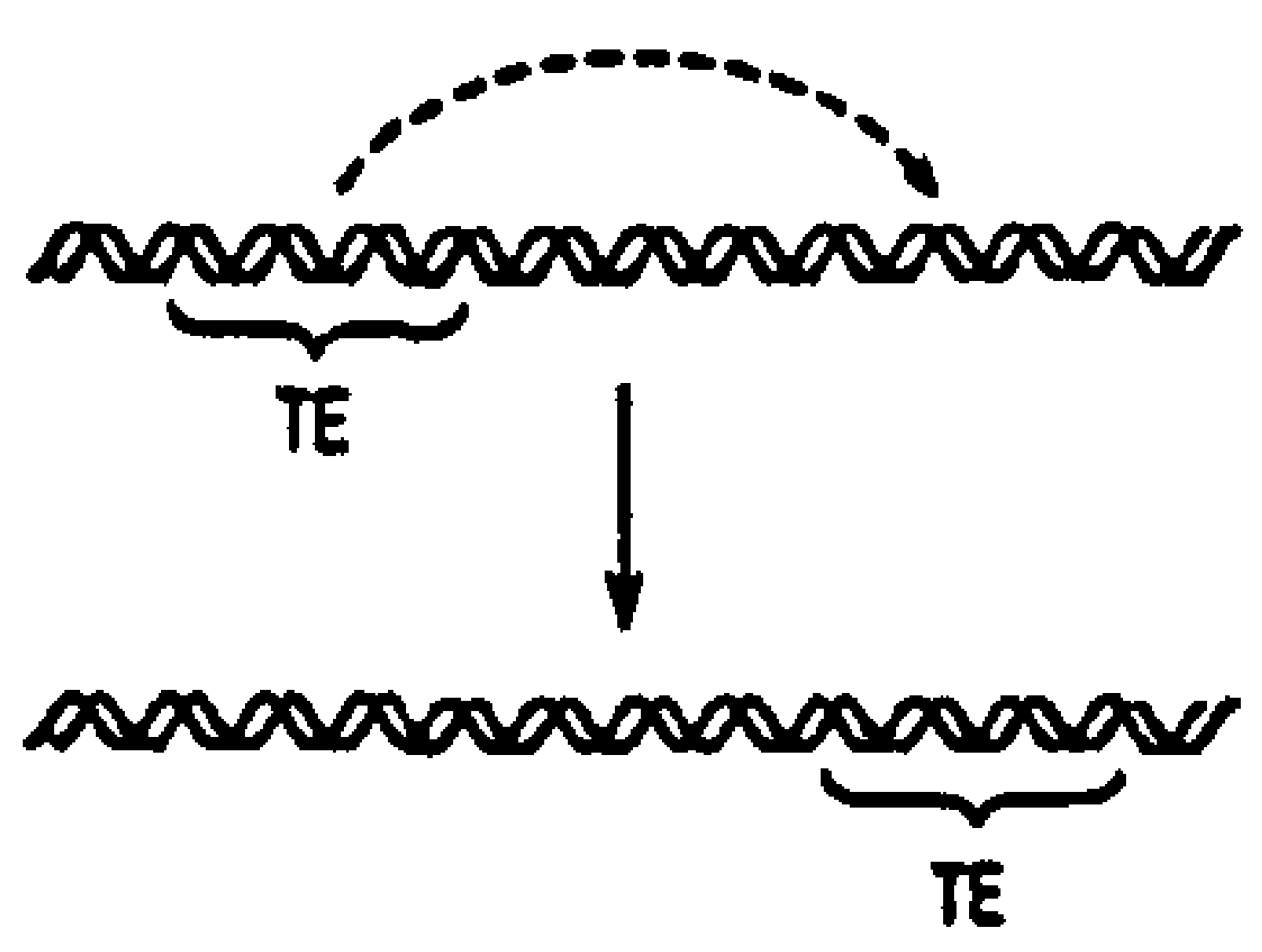
Composite transposon

I'm another transposable element just like transposon and also found in bacteria but I'm sandwiched between insertion sequences. We transposable elements are slightly different in our structure from one another. However, collectively we are called jumping gene. I would like to tell you how we jump or move around. There are three types of mechanisms of transposition but we are looking at just two of them.

Mechanisms of transposition

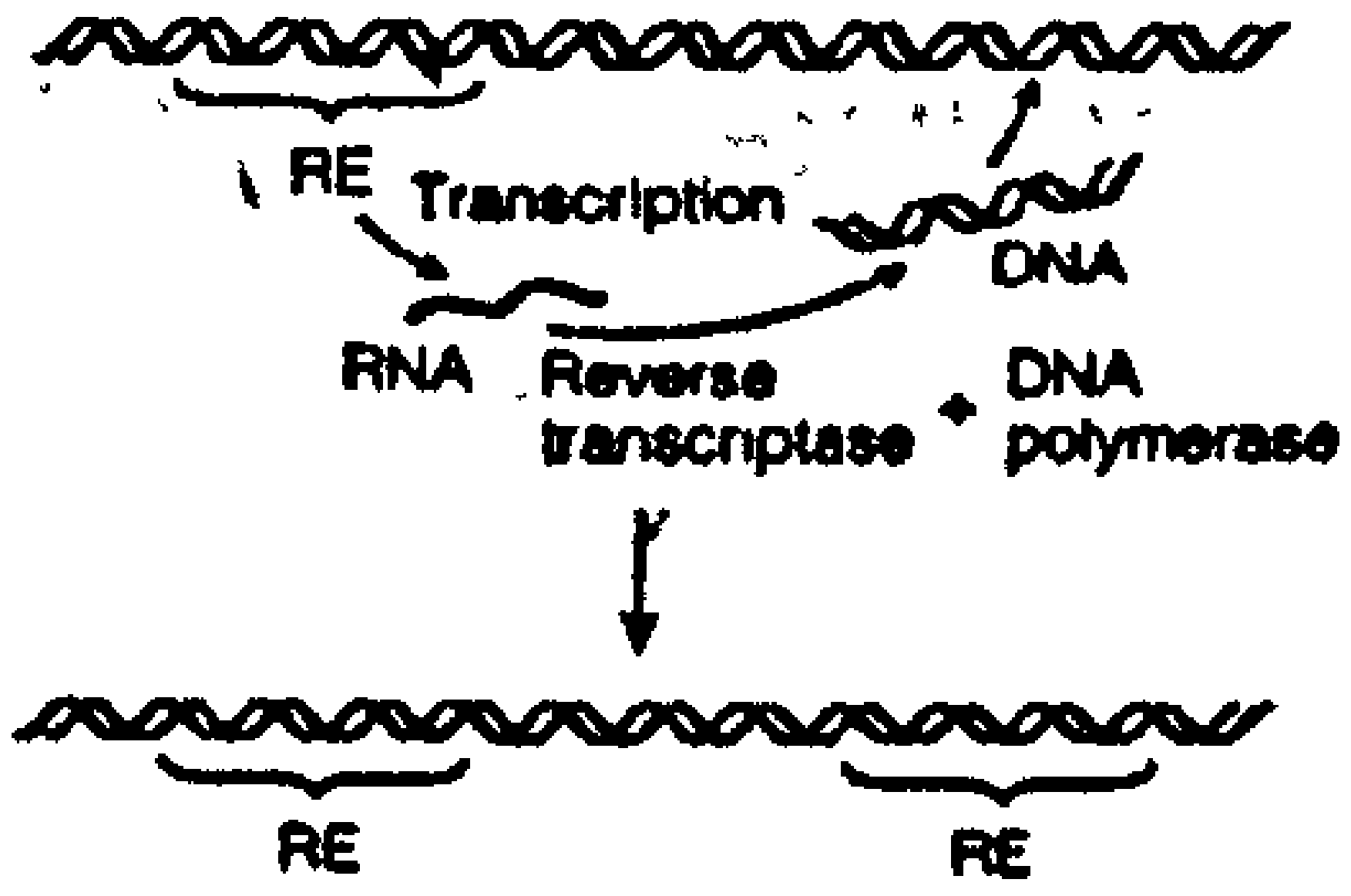
(1) *Conservative transposition*: It is also called the 'cut and paste' mechanism of transposition where the transposable element is inserted into a new position without leaving any copy of it on the original site (see fig 2).

Fig 2: Transposable element (TE) and cut and paste transposition



(2) *Retrotransposition:* This is also called the 'copy and paste' mechanism because the original transposable element remains at the original site while its copy is inserted at a new site (see fig.3). Such element is called retroelement (RE). Copy and paste mechanism increases the number of DNA sequences in the genome causing its size to increase.

Fig 3: Retroelement and copy and paste transposition



Now I would like to tell you about the types of transposable elements on the basis of the mechanisms of transposition. Transposable elements are divided into two groups called DNA transposons and retrotransposons (retroelement). DNA transposons jump by cut and paste transposition. For example DS is a DNA transposon. It increases the size of the gene where it gets inserted but does not affect the genome size because it jumps to a new location without leaving its copy behind at the original site (fig 2). However, retrotransposons jump by 'copy and paste mechanism' (retrotransposition). Copia element in fruit fly, LINE and SINE in mammals are retrotransposons. Retrotransposons increase the gene size where they get inserted however; they also increase the genome size because they jump always leaving their copies behind (fig 3). Human genome project shows that 35–40% of human DNA is made up of retrotransposons. In contrast to DNA transposons most retrotransposons 'jump' only occasionally and there are many, which appear to have lost this ability.

The transposable elements are a threat to the normal activities of true genes because they can introduce mutations by switching on and off the gene activity (see fig.3).

Fig 3: DNA segment showing mutation

Transposition is an important mechanism because it can remodel the genome and is likely to occur in all organisms. It is reported that two modern medical tragedies, integration of HIV and antibiotic resistant bacteria into the host genome, are largely because of transposition.

Well, I have a lot more to tell you about myself but not for this session. I'll explain further details about myself some other time.

Before leaving I would like to recommend you to look at the compact summary on the next page. It will help you to understand my place in this big biological world and will also be useful for you to see your own place and other organisms' position. It will also show the biological organisation of multicellular and unicellular organism.

Unit 2

Joseph's Coat

The Speckled Corn Seed

Hello,

I'm a corn seed from Mexico. I am speckled (spotted) in colour and my yellow, purple, black and blue siblings call me Joseph, the favourite one, because of my multi-coloured coat: everybody said I was the most beautiful. The pattern of hues made me different from my siblings and caught everyone's attention. You might have heard of Joseph, a person mentioned in the Bible, who was given an exquisite coat by his father because he was very dear to him.

Although, I liked my coat with its marvellous colours and enjoyed the compliments, I was very curious about the origin and the nature of these coloured patterns. I found that a famous researcher, Barbara McClintock, was investigating the colouring pattern of corn seed. Out of curiosity, the very next day I went to see her.

To my horror, she told me that my lovely speckled coat was because something went wrong with my genes. When I heard that, I was shocked and did not listen to the rest of what she was saying. She talked about levels: cellular levels, organ levels etc. She mentioned two worlds: microscopic and macroscopic.

A few days after my visit to her, I received a letter telling me that she had written an article about the origin of my coat for a journal. She sent me a simplified version to make sure that I understand it. I think it will be quite useful for you as well if you really want to understand. I have brought a copy and would like to give it to you

Let's read it!!

The Speckled Corn
Described from the work of Barbara McClintock

Every trait or phenotype, of an organism needs to be studied both at the microscopic and the macroscopic levels. Certain features of an organism can be seen with your naked eye but others need some kind of technical aid like a microscope. Any phenotype you observe in an organism has its root in microscopic world. Similarly, whatever happens in microscopic world has consequences in macroscopic world. It means that these worlds are linked.

Every organism can be seen as a system composed of different levels of biological organisation: organ, tissue, cell, chromosome, gene and molecular levels. Similarly, a number of individuals of the same species make a population and where the different populations interact we have a community. All populations and communities and the environments they inhabit constitute an ecosystem.

To understand a phenomenon, it often helps to use an imaginary level ladder described on page 4. I'll explain about the speckled (spotted) corn seed with the help of this ladder. I have worked on corn seeds for a long time and I was curious to find out the cause of the speckled corn seed. It is known that the wild corn colour is purple or blue while the mutant is yellow. Mendelian genetics would imply that genes never mix together resulting in variegated corn seeds. According to Mendelian laws of hereditary corn seed can be either purple or yellow. However, this speckled seed was a kind of a defiance of the established laws of genetics. That triggered my curiosity.

I wanted to study the speckled seed and my investigation started at organ level (Corn cob & seed). See page 4.

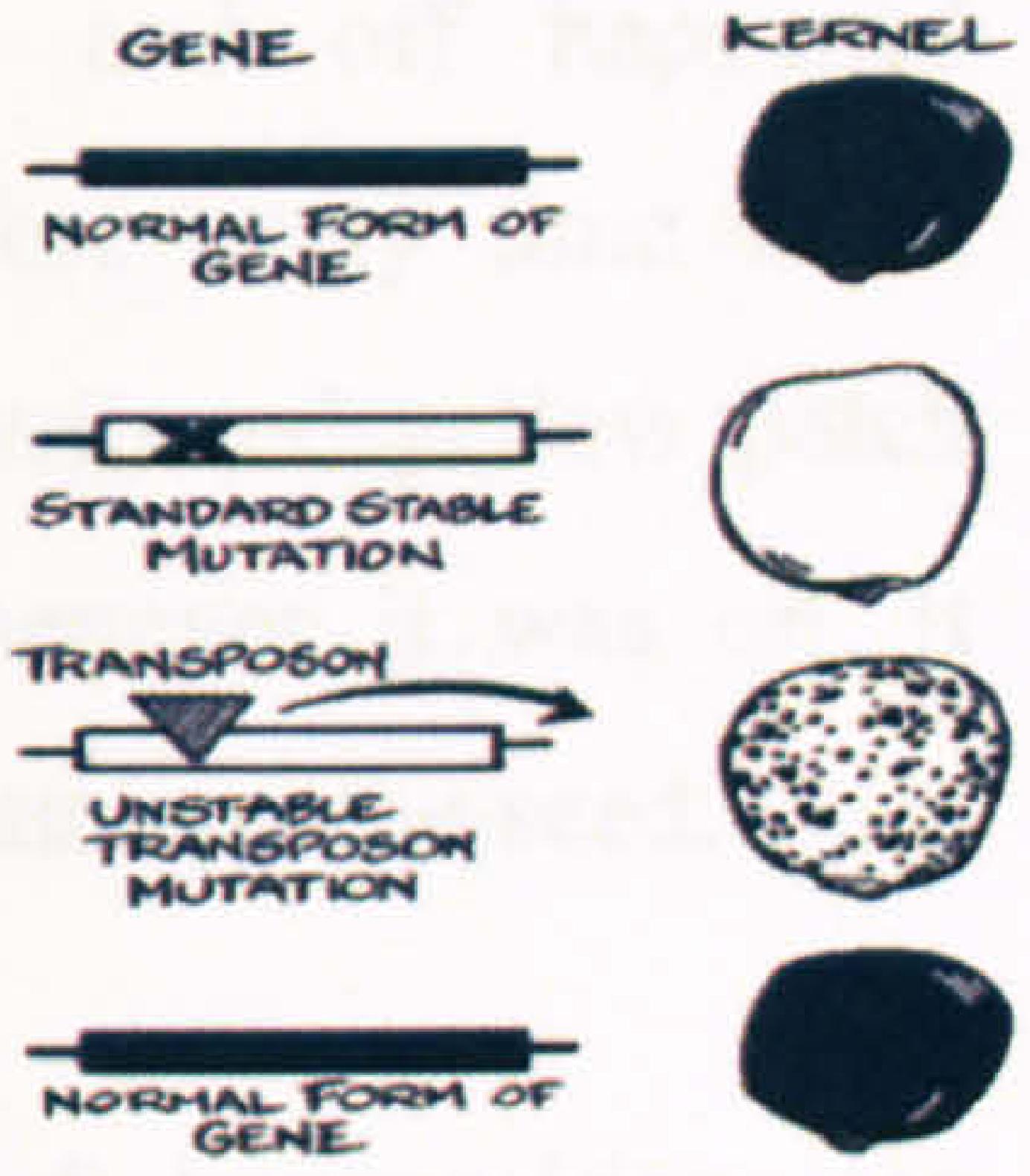
As I told you these levels are connected and cannot be separated and studied in isolation. However, one has to start somewhere and need to draw a boundary around investigation. This is what I did because I could not study everything.

Speckled corn seed is a part of a corn cob (a sort of an organ) of the corn plant (organism) therefore in this way it is connected to the organism level. It cannot exist on its own. Next to the organ level, comes the tissue level, consisting of all the cells comprising the corn seed. Since the cells are all fairly similar, I selected one cell from the tissue level and then my investigation moved to the next level called the cellular level (See page 4).

Cells are complex but I knew that genes that control traits exist within their (cells) nuclei and therefore I had to take my investigation further down into the nucleus. Inside the nucleus my investigation focussed on chromosomal level. The next stage was to find out which chromosome was involved in the production of speckled corn seed because there were so many of them. The short arm of the chromosome # 9 became the target of my observation. However, it was not possible to find the answer by remaining at the chromosomal level. Investigation had to be done further down at the gene level.

The gene responsible for dark purple colour of corn seed is a wild type phenotype and the gene responsible for it is gene C called normal gene or wild type gene. The yellow corn is a mutant type and it is controlled by a mutant gene c in which the normal function has been stopped. In the case of speckled corn, the gene causing coloured patterns is also present on chromosome # 9. However, something else was going on which made it different from the other seeds, as it seemed to be both producing and not producing the purple pigment. At this point I went further down beyond the chromosomal level to carry out my investigation on gene level.

But before I explain what I discovered let me give you some information about gene level. The genome (all the genes in an organism) is like a community of genes and every gene has a fixed position or a permanent address within a specific chromosome. However, there are some genes which do not have fixed locations and they roam about the genome like gypsies. They are called transposable elements or jumping genes.



The exciting bit of my investigation was that the discovery of these transposable elements helped in explaining the unusual speckled trait of corn seed. In case of corn genome, a transposable element is composed of two components: Ds and Ac. Both are present on chromosome #9 where gene C for pigment control is located. Ds is categorised as a DNA transposon. Ds can jump from one place to another by a conservative mechanism of transposition also called cut and paste transposition. But its (Ds) mobility depends upon the presence of Ac because Ac codes for an enzyme called transposase that initiates transposition. In its absence Ds cannot move.

Now let me explain to you that the understanding of transposable elements helps in explaining the speckled phenotype of the seed. Suppose gene C is residing on its specific location on chromosome # 9 and performing its function of coding for purple pigment for the corn seed. If it is left alone it will perform its normal function.

Now, suppose that a transposable element (Ds with the help of Ac) jumps around and lands on the position occupied by gene C splitting it in two parts by inserting itself into the middle of the gene. The result of this insertion is the conversion of gene C (wild type) into gene c (mutant). The Ds has switched off the normal activity of gene and it stops coding for purple pigment. If Ds remains inserted into this gene it will be a stable mutation and the result of this mutation will be a yellow corn seed.

However, what happened with speckled seed was something different. It was an unstable mutation because during the developmental stage, Ds inserted itself into the gene C (wild type) and switched it off thus stopping it to code for purple colour thus converting it into gene c. After that DS jumped out of gene c and resulted in the switching on of the gene and it started coding for purple colour. This switching on and off happened several times therefore every time when gene was off it contributed yellow patch to the seed and whenever it was on, it contributed purple patch on the seed.

The phenomenon of transposition can cause stable and unstable mutation. The result of stable mutation will be yellow corn seed but unstable mutation will produce speckled corn seed. This is how Joseph, the speckled corn seed, got its beautiful coat.

The next page shows the levels as they apply to a corn seed. It will help you to visualise the levels. I hope this make understanding easier for you.

Unit 3

Ugly Sam

The Secret of the Wrinkled Pea Seed

Hi,

My name is Sam and I'm a wrinkled breed of pea seed and you are one of Dr. Paterson's students from the University of Strathclyde. Well, I'm pleased to meet you. Let me tell you about myself. I'm certain that you know about Mendel's work on round and wrinkled pea seeds. Mendel had two pure breeding lines of plants: one that always gave rise to round peas and another that always gave wrinkled ones.

Did you know that the round seeds have higher starch content and so are used to make pea soup? The wrinkled seeds have different carbohydrate content and so are used as a fresh, frozen, or canned vegetable.

I came into being because of a jumping gene. Of course this was not known at the time, but the analysis of the mutation (wrinkled appearance) using modern methods has revealed the function of the gene at the molecular level. Now I can tell you how I got the name Sam.

Last year in a seed exhibition, a seed company was displaying garden pea seed varieties. In this exhibition, an amateur gardener was examining a handful of wrinkled pea seeds. I was one of those wrinkled seeds. Having had a close look he dropped the seeds back into the packet and mumbled. ……"Disgusting…ugly Sam". I was shocked hearing this remark, but was not sure about why he called us Sam. Soon after that, I overheard him explaining to the seller that Sam was the ugliest dog in the World.

Now let's travel to the microscopic world to see how I became wrinkled. Before we start, remember: Make sure you use the conceptual level ladder (page 5) that was introduced in the previous unit. The tour information package will guide you into the microscopic world. This package includes a guidebook (page 2-3) and a map (page 4). Follow them carefully and you will not get lost.

Remember

It is customary to call the most common form of a trait occurring in natural population as the *wild type* . Any form that differs from the wild type is considered to be a *mutan* t. In case of pea seed shape, the wild type is round and mutant type is wrinkled.

The wild type and mutant forms of the gene are represented as *W* & w respectively. It is also customary to print the gene symbol in Italics. Geneticists use the mutant characteristic to name the trait. A capital letter often identifies the dominant form and lower case the recessive.

If you want to understand and learn about the link between the wrinkled peas seed and the jumping genes, you are recommended to use this text along with the map you have been given.

During this tour you will start from the macroscopic world and then descend down into the microscopic world.

"A Guided Tour across the Levels"

By

Ugly Sam, the Wrinkled Pea Seed

You will have to start from the 'organ level' (marked as *2 on your map). I, Sam, the wrinkled seed belong to this level and can be found in a pea pod. However, I am not all alone here. I have contacts and links with the other levels as well. I was born on a pea plant (organism) and to watch this plant you will go to the 'organism level' (marked as *1 on your map). On this level, you will find pea gardens blooming and spreading sweet fragrance. I was born out of these flowers and was wrapped up in a pea pod.

Now get ready and move on to your level ladder and this time you can by pass the 'organ level' and your next destination will be 'tissue level' (marked as *3 on the map). This level is the last in the macroscopic world and it is not an interesting place. You will find it quite monotonous and boring because the cells at this level are identical in almost every aspect. Let's move on to the next level.

Your next stop will be the cellular level (marked as *4). This level is full of liquid, mostly water (called cytoplasm) and it appears as a big pond. Therefore, you need to put on your waterproof and wellies. Now, look at your map and you will see that you have to cross two borders before you find yourself at the cellular level in the cytoplasm pond. The first border is the cell wall (shown as □1) and the second border is the cell membrane (shown as □2). Now you are in the cytoplasm pond (shown as ■1). This is a big pond with lots of structural and chemical components, bustling with all sorts of activities.

Look quickly at certain very important structural and functional components (cell organelles). These important structures have been marked on your map. I would like you to see the fantastic 'power house' (mitochondria: ●2), a protein generator (ribosome: ●5), the 'water pressure controller' (vacuole: ●3), the transport system of channels (endoplasmic reticulum: ●1), and finally the 'control centre' (nucleus: ●4) of the cell. Now we cross the border (marked as □3) to enter into the nucleoplasm pool (marked as ■ 2).

While you are in the nucleoplasm pool, you will see lots of rope-like structures called chromosome that means that you are now at the chromosomal level but, as there are so many chromosomes, you cannot go to each one of them. You will look for one particular chromosome (marked on guide map as *5). Find this chromosome. This chromosome will be flagged with a 'gene w' that is responsible for the seed shape. At the spot marked as 'gene w' you need to use your powerful binoculars and you will see the 'gene level' marked as *6.

At this level, you will find out what caused Sam's body to be wrinkled, the reason for this trip. You will find that 'gene w' is not normal. It is mutated because it is not intact. You will recognise that the gene w is not normal because it is divided and is sandwiching another sequence of DNA, called transposable element or jumping gene. The transposable element has interrupted gene activity by changing the wild type 'gene W' to the mutant 'gene w'.

The insertion of jumping gene has changed the gene in two ways: firstly, the size of the 'gene w' is bigger than 'gene W' because of the insertion of transposable element (marked as *6). Secondly, it has affected gene activity and made it unable to perform its normal function. The result of altered gene activity can be observed at the organ as well as at the molecular level (marked as *7). At molecular level, you have to use your knowledge from chemistry class. The explanation is in the coloured box. Make sure you read the text in the blue box.

This is what happened to me and every other wrinkled seed. Now you will be able to link the changes at molecular level to those at the other levels. The table below shows that all levels are connected. Therefore, no level can be studied and understood in isolation. We have to move upward and downward on the ladder to develop understanding.

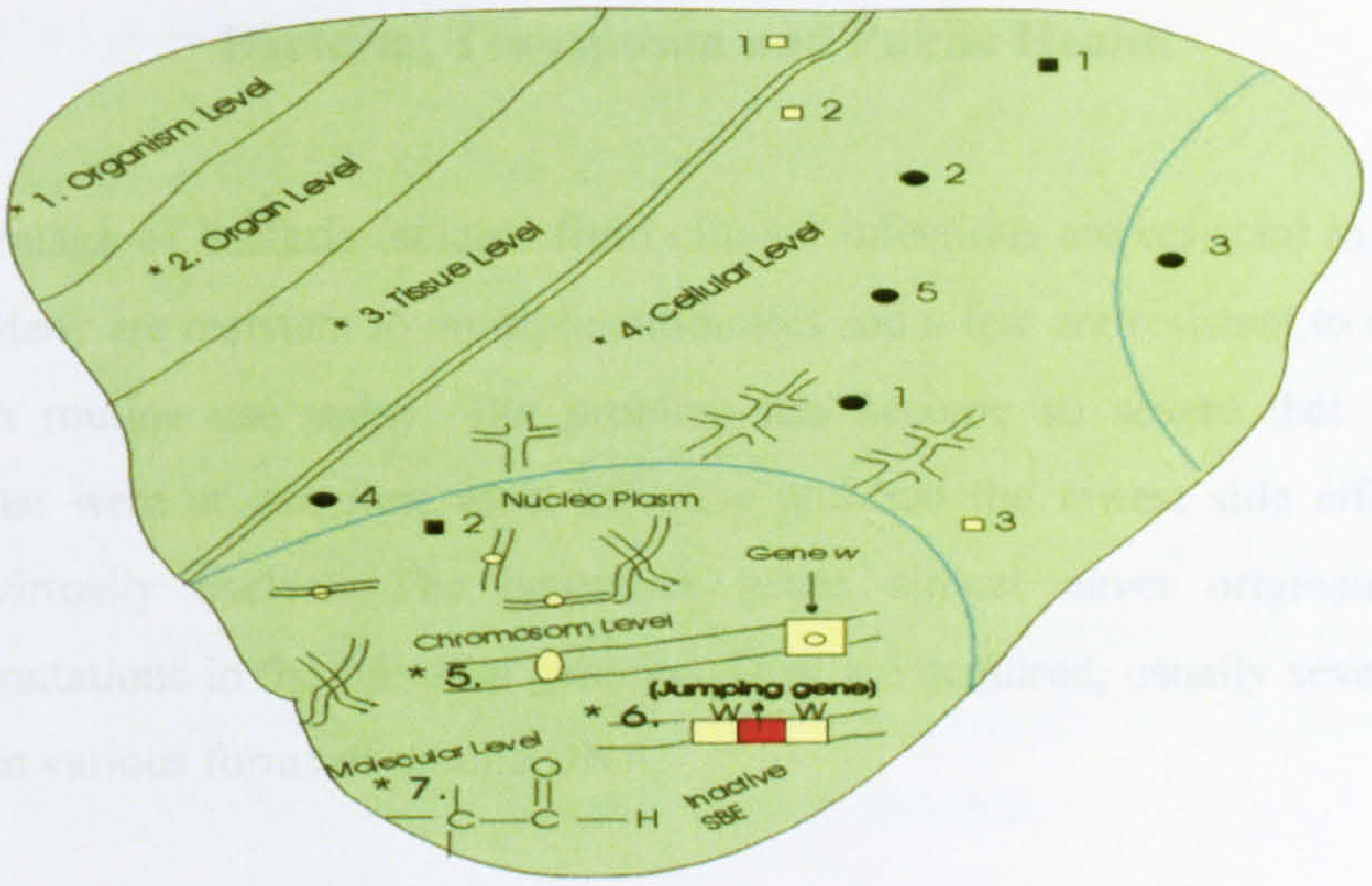
Table 1: Different levels and their components involved in case of wrinkled and smooth pea seeds.

Levels	**Round seed**	**Wrinkled seed**
GeneneLevel (*Gene size*)	W (Wild type) Normal size but smaller than gene w	W (mutant type) larger in size than gene W (wild type)
Molecular level (*Enzyme*)	Active SBE-1	Inactive SBE-1 (Transposase enzyme)
Cellular level (*Starch type*)	Amylopectin (branched star) synthesis	Amylose (linear starch) synthesis
Organ level (*Seed phenotype*)	Seed dries uniformly and becomes round and smooth	Seed does not dry uniformly and shrinks and becomes wrinkled

Actually, normal gene ***w*** (wild type) encodes for an enzyme called starch-branching enzyme (SBE-I), which helps in the synthesis of a branched chain starch, called amylopectin. It has got the ability to retain water. When pea seeds dry, they lose water. If they have branched starch they shrink smoothly and end up being smooth and round. However, this is not the case with the gene w because it is not normal.

*Gene **w*** produces an inactive enzyme (SBE-I). In the presence of inactive SBE-I, the linear starch, amylose, is synthesised and this cannot retain water as does amylopectin. Therefore the seeds with amylose lose water and, as they dry, they do not shrink uniformly and this results in a wrinkled shape, a phenotype different form the wild type.

Map for the 'Tour across the Biological Levels'



Symbols used in maps

*	Biological levels
□	Borders (cell wall and membranes)
●	Important structures (cell organelles)
■	Ponds (liquid filled area)

Directory to levels

*1	Organism level (garden pea plant)
*2	Organ level (pea pod & wrinkled seed)
*3	Tissue level (multitude of cells of pea seed)
*4	Cellular level (one cell of a pea seed)
*5	Chromosomal level (chromosome carrying 'gene w')
*6	Gene level (mutant 'gene w')
*7	Molecular level (lacking enzyme SBE-I)

Directory to borders

□1	Protective wall (cell wall)
□2	Border (cell membrane)
□3	Border (nuclear membrane)

Directory to important structures at cellular level

●1	Transport system of channels' (endoplasmic reticulum)
●2	'Power house' of the cell (mitochondria)
●3	'Pressure controller' (vacuole)
●4	'Control centre' (nucleus)
●5	'Protein generator' (ribosome)
■ 1	Cellular pond (cytoplasm)
■ 2	Nuclear Pond (nucleoplasm)

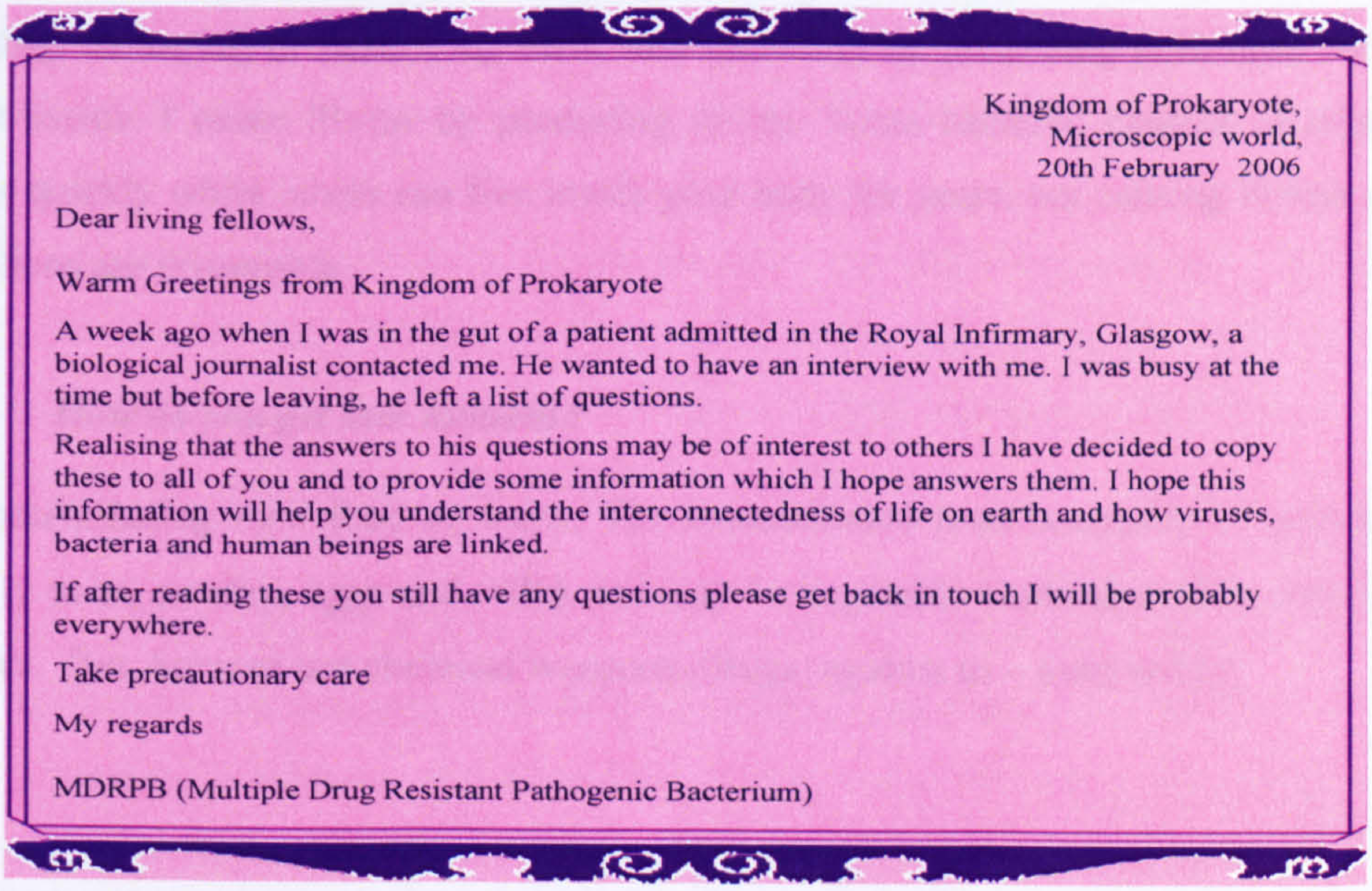
Unit 4

Bacteria, Transposon and Public Health

A high percentage of bacteria isolated from clinical infections are resistant to one or more antibiotics. Many are resistant to multiple antibiotics and a few are resistant to almost all the antibiotics in routine use today. The problem has become so severe that many of the antibiotics that were at one time most effective and had the fewest side effects are now virtually useless. The resistance genes almost never originate from new mutations in the bacterial genome. They are acquired, usually several at a time, in various forms of mobile DNA.

In nature a conjugative plasmid (a plasmid that can be transferred to the other bacterium through conjugation) can accumulate different transposons containing multiple independent antibiotic resistance genes with the result that the plasmid confers resistance to a large number of completely unrelated antibiotics. These multiple drug resistance plasmids are called R plasmids.

Serious clinical complications result when R plasmids (resistant to multiple drugs) are transferred to the pathogenic bacteria (agents of disease). Infections with pathogens (bacteria) that contain R plasmids are extremely difficult to treat because they may be resistant to most or all antibiotics currently in use. Pathogenic bacteria are having a great time and here is what one of them might be saying, if (s) he ever could be interviewed!



Kingdom of Prokaryote,
Microscopic world,
20th February 2006

Dear living fellows,

Warm Greetings from Kingdom of Prokaryote

A week ago when I was in the gut of a patient admitted in the Royal Infirmary, Glasgow, a biological journalist contacted me. He wanted to have an interview with me. I was busy at the time but before leaving, he left a list of questions.

Realising that the answers to his questions may be of interest to others I have decided to copy these to all of you and to provide some information which I hope answers them. I hope this information will help you understand the interconnectedness of life on earth and how viruses, bacteria and human beings are linked.

If after reading these you still have any questions please get back in touch I will be probably everywhere.

Take precautionary care

My regards

MDRPB (Multiple Drug Resistant Pathogenic Bacterium)

Frequently Asked Questions about Bacterium (Salmonella typhimurium)

Q ***Tell us something about yourself***

I'm a foe not a friend of yours because I'm a pathogenic bacterium. I'm bacillus (rod shaped). My name is Salmonella typhimurium. I possess a linear DNA strand and also a small circular DNA called a plasmid. I reproduce by binary fission very quickly and can increase the number of my colonies very rapidly. However, I also have a kind of a sexual life as well, known as conjugation. My fame is for causing salmonellosis (food poisoning) in human beings. I'm heterotrophic because I cannot manufacture my own food. I therefore live off hosts in the intestinal tract of humans, animals and birds.

Q ***Why are you causing havoc by causing salmonellosis?***

Well, that is unfair. I'm just leading my life. Every single living species has a right to live and multiply. This is what I'm doing. For me, it is good to see my colonies, my children, growing and flourishing.

Q ***What are the symptoms of salmonellosis in humans?***

Human salmonellosis is usually characterized by acute onset of fever, abdominal pain, diarrhoea, nausea and sometimes vomiting. In some cases, particularly in the very young and in the elderly, the associated dehydration can become severe and life threatening.

Q ***Let me ask you, how bacteria, in general, cause illness?***

Bacteria can make you ill in two ways. Firstly, by spreading throughout your body and invading, damaging or destroying cells, and secondly, by producing poisonous substances called toxins. I cause illness by producing toxins. Some bacteria, cousins of mine cause illness quickly while others can live inside your body for years, not causing illness until the conditions are favourable.

Q ***How do you get into humans?***

By contaminating their food or water. The contaminated food is usually of animal origin (mainly meat, poultry, eggs and milk), but may be vegetable contaminated by manure from animals. But, humans use chemical weapons (drugs) against us – most unfair.

Q *Have you heard of miraculous drugs called antibiotics?*

Yes, of course. No one knows about antibiotics, better than I do. Humans used to call these drugs the 'crown jewel' among drugs. But now many of them are not effective against us.

Q *Why is that?*

We are very clever! We can stop the antibiotic from getting to its target by not allowing it to be absorbed. We can change the structure of the target that the antibiotic can no longer recognize it or bind to it. Sometimes, we can even destroy the antibiotic. I am well defended but you humans are very clever. Who knows at this very moment a new killer is waiting on the shelf to be used against me.

Q *What about viruses? How do they affect you?*

Yes, virus can be a serious threat to life of bacteria. Viruses that live inside me are called bacteriophages. The virulent bacteriophages can kill me but temperate bacteriophages can insert their genetic material into my chromosomes and then it replicates along the bacterial genetic material. Sometimes this insertion helps me because viral DNA can carry genes for antibiotic resistance.

Q *Will you tell us how did you become a multiple drug resistant pathogenic bacteria?*

Well, I'm pathogenic because I can cause illness, and am resistant but against certain antibiotics used to kill the bacteria. Presently, I'm resistant to four antibiotics because I have an R plasmid, which means my plasmid is carrying genes resistant to four antibiotics. Basically I have received these genes mostly through transposons.

Well, I have to start from my birth. My parent, who was resistant to antibiotic 'A' was living in a contaminated water pond in a garden and went through binary fission producing two identical bacteria. I was one of them. I received a gene resistant to antibiotic 'A' and so therefore from the beginning I was resistant to one antibiotic.

As soon as I started my life, I felt a pinch on my back and I knew that it was a bacteriophage. I thought that my life was over because bacteriophages are notorious for taking control over bacterial genetic machinery and eventually killing them. However, fortunately it was a temperate bacteriophage. It did not harm me, but quietly managed to get inserted in to my circular DNA (Plasmid). The moment it injected its genetic material into my body I found that its genome was carrying a gene for resistance against antibiotic 'B'. In this way I became resistant to two antibiotics.

One day, the owner of the garden watered the lettuce with the water from the pond. Then she picked these lettuce leaves for dinner, washed them but I managed to hide somehow on the leaves. Next I found myself in her intestinal tract. There I met a non-pathogenic E.coli. We lived in harmony even though we were competing for food. Anyway, E.coli was good to me as it was harbouring a gene resistant to the antibiotic 'C' on its conjugative plasmid. One day it approached me and we had conjugation and I got its conjugative plasmid along with the gene resistant to antibiotic 'c'. In this way I became resistant to three antibiotics.

Finally one day in the gut of my host I saw salmonella, which I knew, was from a cow. He did not stay there long but, before being expelled, we conjugated and I received another plasmid-carrying gene for resistance against antibiotic 'T'. In this way I became a multiple drug resistant pathogenic bacterium. You can see how all life is connected on earth. The key for me is to know how everything fits together so that I can survive. Now I'm off to multiply again.....you can meet us all later! .

Salmonella

Please read the following before you read Unit No 1

This booklet has been designed to help you in developing understanding about the phenomena of transposition involving different levels and different components.

The major purpose of this booklet is to make you know that the knowing of the different levels of biological organisation is important for developing understanding. Whatever is studied, researched and taught is related to these levels.

✧ See the diagrammatic summary given to you.

These levels give an indication that it is important to think in levels and be aware about the links and connections between different levels. At each level different element are involved therefore it is important to see that these elements are related and linked together. It means that it is needed to link these levels by thinking in levels. This booklet will help and guide you to see and learn the biological phenomena in a way that is different from your text book style.

Do not get surprised as you read this book let, it will remind you the stories you heard and read in your child hood where animals and unanimated objects would speak the human language and teach you a moral lesson. (Although you know that animals can not speak). Similarly, in this booklet you will read the talks of some biological components: genome, and transposable element.

You know that genome and genes can not speak like human being however; it would be helpful to you if you imagine all these things while reading this unit and try tot think and see things in terms of levels of biological organisation. Let me tell you about certain signs used in the book let.

This little figure is your Instructor, and this figure beside the text will be instructors' speech.

🔊 This sign will represent the talk of the genome from the biological world

✉ This sign will represent the talk of two transposable elements from the sub cellular level

Let's read it

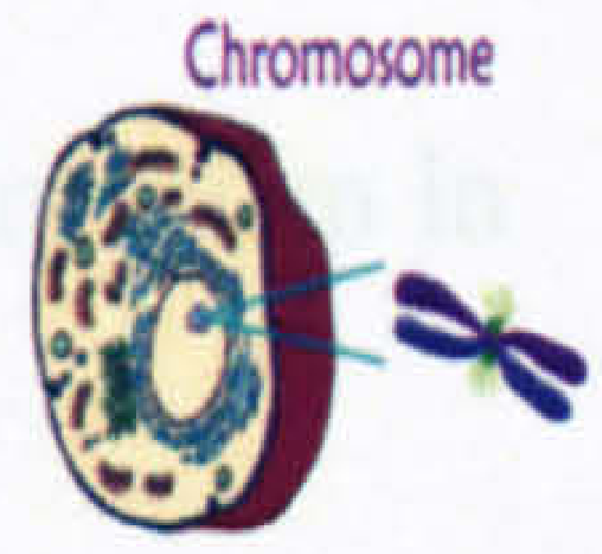
Unit No.1

Genome and Transposable Elements

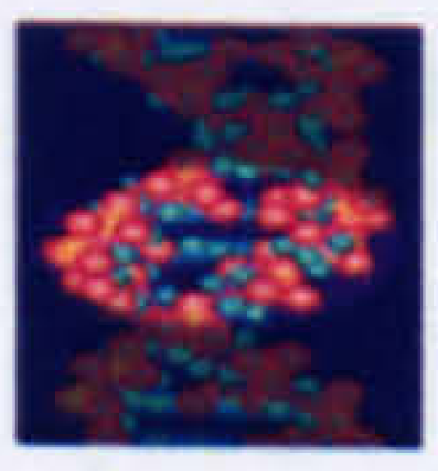
Guests from Faraway

Guest: Human Genome

Hello, I'm human genome and belong to sub cellular level, the molecular level, of biological organisation. I'm sure you have heard about human genome. I'll give you a brief description of myself. There will be something new in the following paragraphs which you might never have heard of.



All the living organisms (multi-cellular or unicellular) have their own genome at sub-cellular level within the nucleus. I'll tell you what genome is? Genome is the total genetic material contained in a haploid set of chromosomes of an organism. In my case, I'm composed of 23 chromosomes. I'm sure you know that chromosome is a long DNA molecule and some associated proteins and thus belongs to the molecular level. In your imagination if you zoom in, on the chromosomes at the molecular level, then you will notice that chromosome is divided into genes. Thomas Morgan was the first who described genes as beads on the length of chromosomes, each with a fixed position.



What is a gene? At molecular level if you zoom in further on the chromosome you can recognise gene there! A gene is a section of DNA segment that is used in producing a particular protein. There are two strands of DNA in each chromosome which are wrapped around each other. The nucleotides in one strand always lie opposite in the other according to the rule. Adenine pairs always with Thymine and Guanine always pairs with Cytosine. Two such complementary nucleotides make a base pair. I am (human genome) 3 billion base pairs.

Now let me tell you what is the function of gene? Genes code for proteins, and there are 100 000 or so proteins making the human body. But there are certain segments of DNA that do not code for anything and therefore are not genes in the real sense. Such DNA segments for which no function has been identified are generally called junk DNA. Apart from this, there are certain segments of DNA which do not have a fixed place but are mobile and move around the genome. Such DNA segments can be found in prokaryotes as well as in eukaryotes.

As I mentioned earlier, Thomas Morgan described that genes on chromosomes have fixed position. However, an organism's genome is not absolutely fixed from the beginning to the end of its life. It keeps on changing. Mutations occur and change the genetic material; sometimes viral genes get into another organisms' gene and bring about changes in the genome. Sometimes rearrangement of genetic material also takes place due to the movement of certain DNA segments. All these changes happening at the sub-cellular level have their effect on the cellular as well as on the higher levels. In the same way higher levels affect these lower levels.

I think I have given you some useful information about myself, I'll go now. Bye

Now you will read about the mobile DNA segments found in different organism in the following paragraphs

1.2 Transposable elements

Thomas Morgan described genes with fixed location on the chromosome but in the 1950s, Barbra McClintock showed that there are certain segments of DNA which do not have permanent position and move to a new position. As they jump from one place to another therefore they are called transposable elements or jumping genes and the phenomenon of moving or jumping around is called transposition. These transposable elements are mobile in the sense that they can insert themselves throughout the genome. Most transposable elements are present in non essential regions of the genome and usually cause no detectable phenotypic changes. But when these elements insert themselves into the functional region of the genome (gene) they bring about gene mutation by affecting gene activity. Therefore transposable elements are also called agents of mutation.

First transposable element was discovered in Corn (Maize) but such elements are also found in the genomes of other organism like bacteria, fruit flies, pea seed and human beings as well. In fact genomes of the most organisms include multiple copies of many transposable elements. For example, 50% of human genome consists of transposable elements most of which have lost the ability to move. Part of the reason why the human genome is so large yet only contains 32,000 genes is that it includes a high proportion of transposable elements.

Now take your work sheet and answer the questions given in the first section.

1.3 Transposable elements in bacteria

Bacteria contain a wide variety of transposable elements. However, there are two simple forms of transposable elements found in bacteria which you will read in the following paragraphs. Suppose they send you a letter telling you about their structure, function and the place in the living world. Let's read their hypothetical letter.

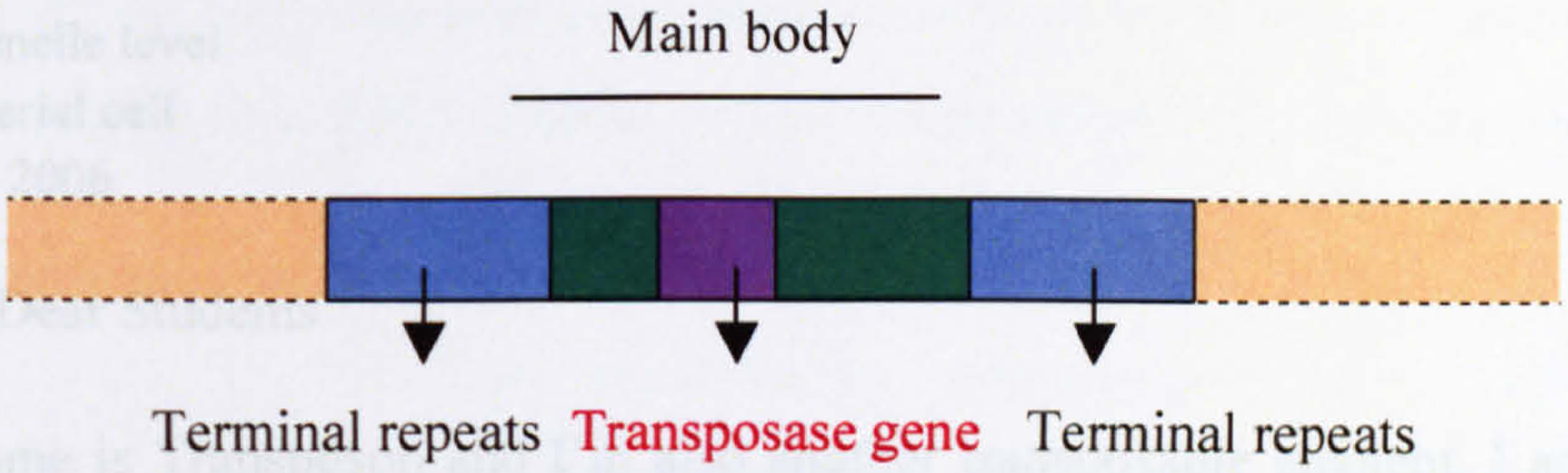
A letter from Insertion sequence

Insertion sequence
Molecular level
Sub-Cellular level
Organelle level
(Bacterial cell)
Dec, 2006

Hello Dear Students

My name is Insertion sequence and I am found in bacterial genome which is a part of a sub -cellular level. I will not mind if you call me IS. Basically, I'm a DNA sequence and do not have a fixed position. I have ability to jump and change my location in the bacterial genome. I'm one of the simplest transposable elements. My body is composed of two parts; firstly a main body and secondly two terminal repeats (See Fig.1). I have attached a picture of me at the end of this text. As you see, my main body is made of many DNA sequences but it has only one gene. This gene codes for a protein (enzyme) called transposase. Therefore it is called transposase gene. This protein is essential for the process of transposition which means that it helps me to move from one place to another. In the absence of this protein I can not move and transposition can not occur. The second part of my body is two terminal repeats surrounding the main body. Just to remind you, terminal repeats are also DNA sequences.

Fig.1: Structural composition of an insertion sequence found in bacterial genome



I live within the bacterial genome and move here and there. To tell you the truth, I do not provide anything useful to the bacterial genome where I come from. However, I can bring about gene mutation by moving into the functional gene by splitting the gene. Thus gene size increases and its function is altered and it becomes mutated. You can see that my presence and activity at the sub cellular level is a threat or danger for the functional gene where I can bring about changes. For example I can change the size of the gene and also can stop or change the function of the gene. These changes in the gene at sub cellular level will bring about changes in the bacteria at organism level. To conclude, my movement and specifically my location within the genome has its effects on the gene as well as on the organism level.

If you want to know more about me, your instructor can help you with that.

Warm greetings
Insertion Sequence

Insertion
Sequence

(b) A Letter from a Tranpsposon

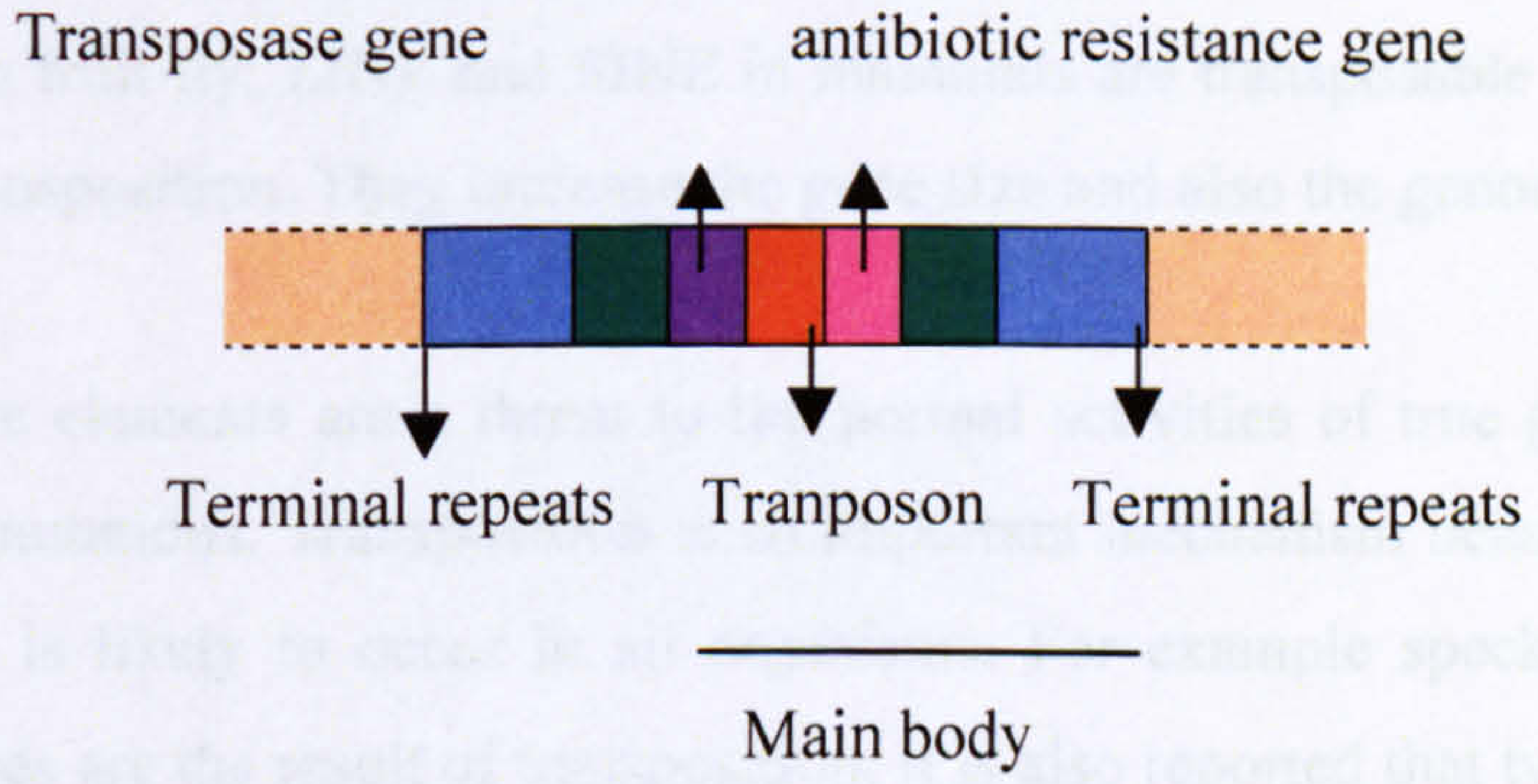
Transposon
Bacterial genome
Sub-Cellular level
Organelle level
Bacterial cell
Dec. 2006

Hello Dear Students

My name is Transposon and I'm also another transposable element. I am also found in bacterial genome and thus belong to the sub-cellular level. I am also a sequence of DNA. My body is composed of two parts. Firstly the main body and secondly the terminal repeats at the both ends of the main body (Fig.2). My main body, like Insertion sequence, has a transposase gene coding for a protein (enzyme) called transposase which helps me to move from one place to another in the genome.

In addition to this, I also have one or more other genes in my main body which are normally responsible for antibiotic (drugs that are used to treat infections caused by bacteria and other micro organism) resistance. In this way I am useful for the bacteria in the survival to fight against the antibiotic. For example I can carry a gene for resistance against tetracycline, Penicillin, Erythromycin etc. (antibiotics), and then bacteria will become resistant and antibiotic will not kill the bacteria. However, if I move into a functional gene of the bacteria then I bring gene mutation by changing its size and function. In this way my composition and my location in the bacterial genome can have impact on the organism level.

Fig.1: Structural composition of an insertion sequence found in bacterial genome



If you want to know more about me, your instructor can help you with that.

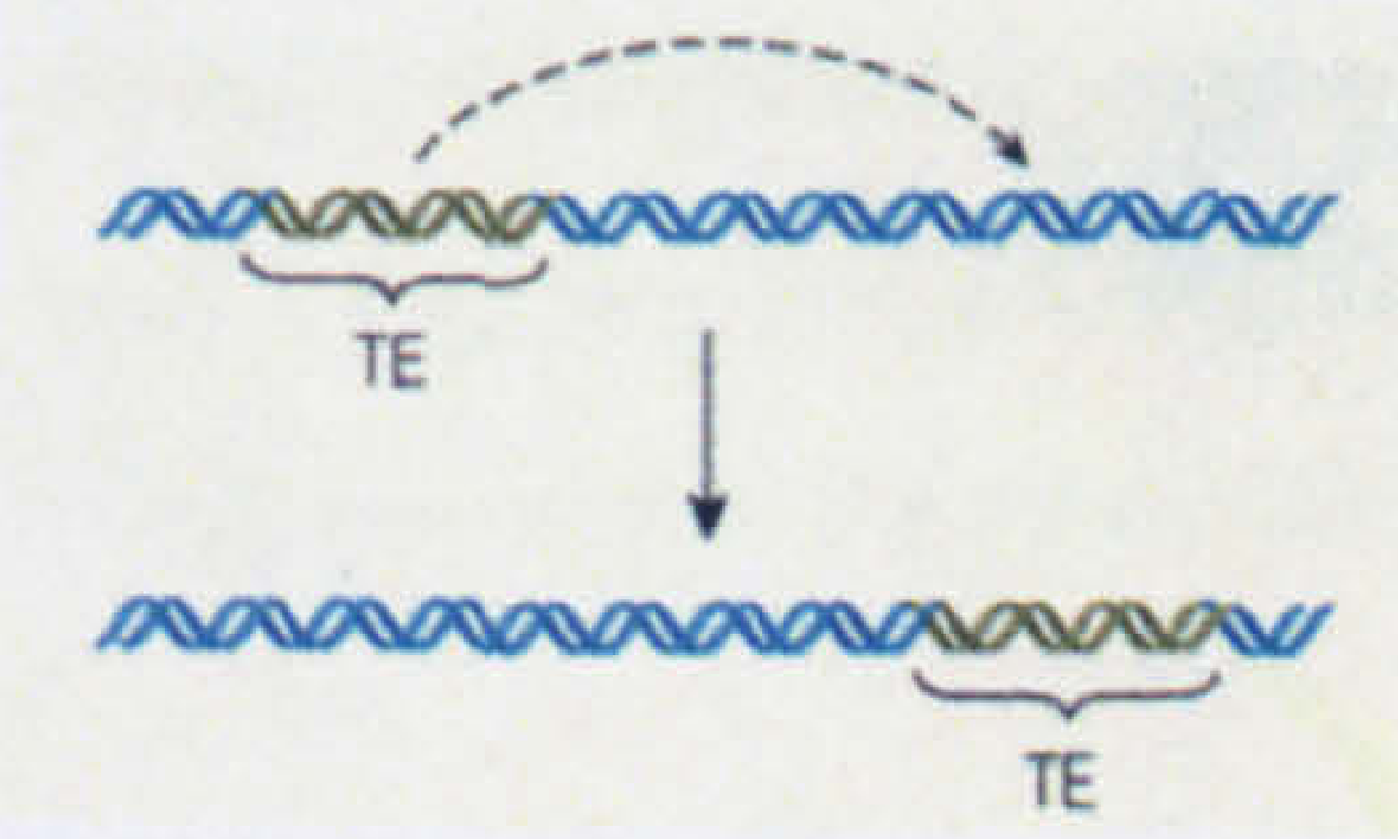
Warm greetings

Transposon

1.4 Types of mechanism of transposition:

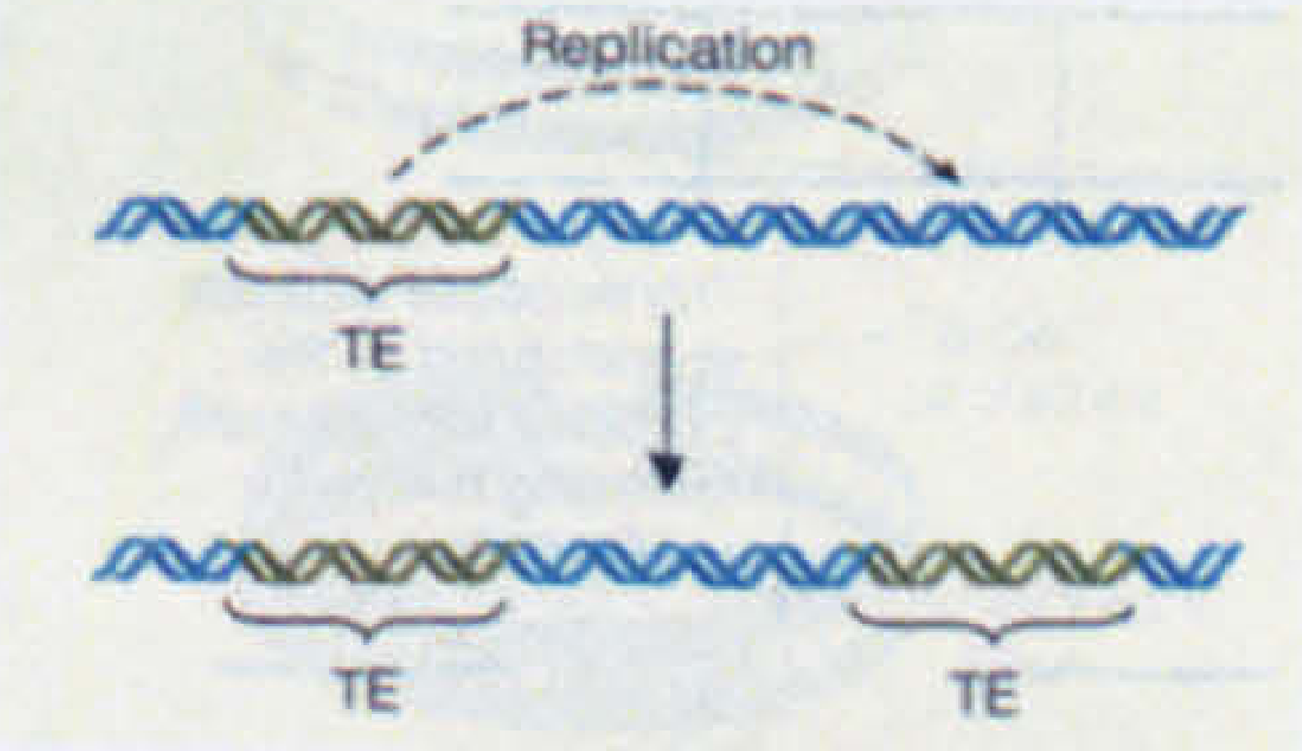
As mentioned above that the phenomenon of transposable elements moving within the genome from one place to another is called Transposition. In the above two sections, you read about structural components of genome the chromosome and genes (molecular level). In the following section you will read about the two mechanisms of the transposition.

(a) Conservative transposition



The conservative transposition is a mechanism of transposition where the transposable element by the help of an enzyme transposase moves to a new position without leaving any copy of it on the original site (see fig on right). It is also called the 'cut and paste' mechanism of transposition which means that the transposable element leave its place and moves into a new location within the genome. It increases the size of the gene but does not affect the genome size because it jumps to a new location without leaving its copy behind. For example DS is a transposable element moving by conservative mechanism of transposition.

(b) ***Replicative transposition***



In replicative transposition one strand of transposable element remains at the original site while the second strand moves to a new site and on both sites the second strand of DNA is formed (see fig at right). This is also called the 'copy and paste' mechanism. Copy and paste mechanism also increases the size of the gene where it gets inserted. In addition it also increases the genome size because such transposable elements jump always leaving their copies behind. Copia element in fruit fly, LINE and SINE in mammals are transposable element and move by replicative transposition. They increase the gene size and also the genome size.

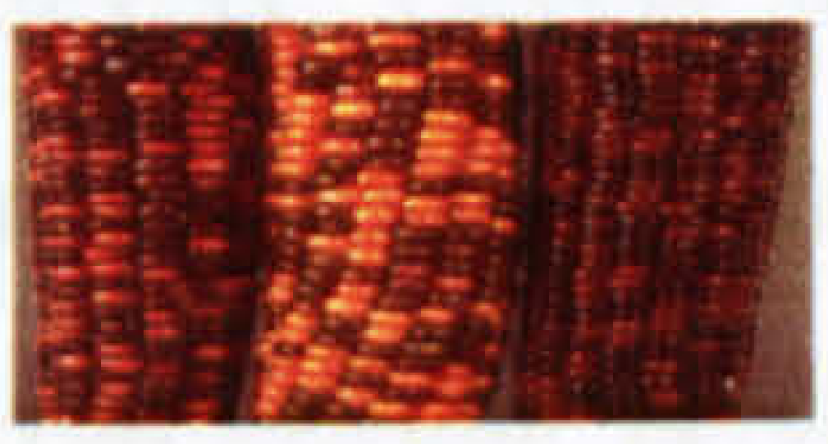
The transposable elements are a threat to the normal activities of true genes because they can cause gene mutations. Transposition is an important mechanism because it can remodel the genome and is likely to occur in all organisms. For example speckled corn seed and wrinkled pea seeds are the result of transposition. It is also reported that two modern medical tragedies, integration of HIV and antibiotic resistant bacteria into the host genome, are largely because of transposition.

Take your workbook and answer the questions

Unit 2

The Speckled Corn Seed

Hello,



I'm a corn seed and have a beautiful seed coat. I am speckled (spotted) in appearance and my yellow, purple, black and blue siblings call me Joseph, the favourite one, because of my multi-coloured coat: everybody said I was the most beautiful. The pattern of colours made me different from my siblings and caught everyone's attention.

Although, I liked my coat (my speckled phenotype) with its marvellous colours and enjoyed the compliments, I wanted to know about the origin and the nature of these coloured patterns. I found that a famous researcher, Barbara McClintock, was investigating the colouring pattern of corn seed. Out of curiosity, the very next day I went to see her.

To my horror, she told me that my lovely speckled coat was because something went wrong with my genes. When I heard that, I was shocked and did not listen to the rest of what she was saying. She talked about levels: cellular levels, organ levels etc.

A few days after my visit to her, I received a letter telling me how the corn seeds become speckled. She sent me a simplified version of her research to make sure that I understand it. I think it will be quite useful for you as well if you really interested to know. I have brought a copy and would like to give it to you

Let's read it!!

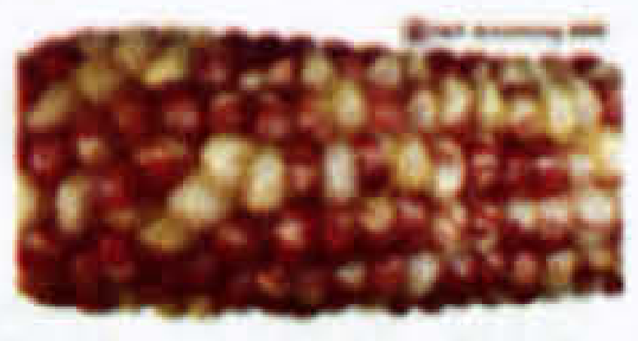
Why is the corn seed speckled?

(1) Hello, I'm Barbra McClintock and I have worked on corn seeds for a long time and was interested to find out the cause of the speckled corn seed. I discovered the first transposable element in corn and was awarded a noble prize for it. I hope the following description will be helpful.

To understand a phenomenon, it often helps to use a model of biological organisation. I'll explain about the speckled (spotted) corn seed with the help of this model (Model 2 at the end of this booklet)

In an organism, the levels of biological organisation can be divided into macroscopic level and microscopic levels. Levels below cellular level are microscopic because they can not be studied without microscope. Every trait or phenotype, of an organism can be studied both at the microscopic and the macroscopic levels because levels are linked by the activities of their components. Certain features of an organism can be seen with the naked eye but others need some kind of technical aid like a microscope. Any phenotype you observe in an organism can be studied at different levels of biological organisation and whatever happens at microscopic level has its effects on macroscopic level. It means that these levels are linked and influence each other.

(2) Every organism can be seen as a system composed of different elements and it is helpful to see them arranged as levels. Levels of biological organisation in an organism can be; organ level, tissue level, cellular level, organelle level and molecular level (chromosome & gene). Individuals of the same species make a population and where the different populations interact we have a community. Communities and the environments they inhabit constitute an ecosystem and different ecosystems constitute biosphere.



(3) It is known that the wild corn seed coat is purple, red or blue while the mutant is yellow. According to Mendel's laws of hereditary, corn seed can be either coloured (purple, blue, red) or yellow because genes never mix together resulting in spotted or variegated corn seeds. So this speckled seed, apparently, was against the established laws of genetics. It made me think why it was so.

As I was interested in the speckled corn seed and wanted to find the answer. My investigation started at the organ level (corn seed). And you know that plants are often recognised to have vegetative and reproductive organs (flowers, fruit and seeds).

(4) As I told you that the levels are connected and at each level there are many components and one has to be selective and need to draw a boundary around investigation. I would like you to zoom in and zoom out in your imagination with the help of the model of biological organisation (model 2) to see the different levels of biological organisation and their components in order to have a clear picture in your mind. Speckled corn seed is a part of a corn cob (a reproductive organ) of the corn plant (organism) therefore in this way it is connected to the organism level because it is part of organism. Below the organ level, comes the tissue level, consisting of a number of cells comprising the corn seed. However my investigation moved to the next level, the cellular level.

(5) Cells are complex but it is known that genes that control traits are present within the nucleus and therefore I had to zoom in to take my investigation further down into the nucleus (organelle level). Inside the nucleus my investigation focussed on genome (chromosome). The next stage was to find out which chromosome was involved in the production of speckled corn seed because there were so many of them. The short arm of the chromosome # 9 became the target of my observation because it was also known that the gene controlling the pigmentation for corn seed can be located on chromosome 9. Therefore investigation at the molecular level had to be zoomed in at that specific gene.

(6) At the organ level, the dark purple corn seed coat is a wild type of phenotype and the gene responsible for it is called normal gene or wild type gene (gene C). The yellow corn is a mutant type and it is controlled by a mutant gene c in which the normal function has been stopped.

In the case of speckled corn seed, the gene causing coloured patterns is the same gene which causes the seed to be purple or yellow. However, something else was going on which made it different from the other seeds, as it seemed to be both performing and not performing the normal function of coding for the production of purple pigment called anthocyanin. At this point I carried out my investigation on that specific gene to observe what happens to that gene. But now my investigation included another element present on chromosome called transposable element.

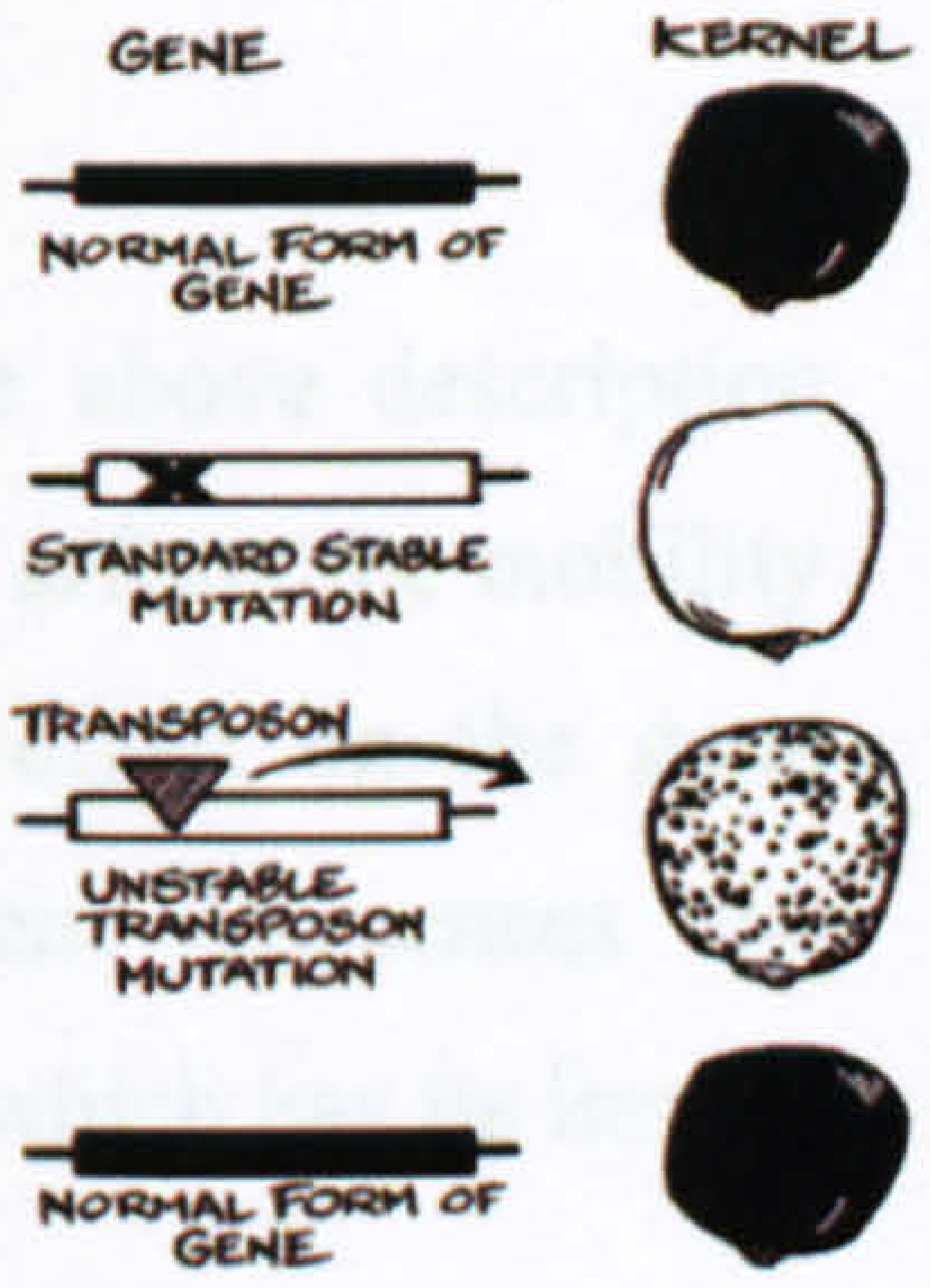
Phenomena at molecular level:

But before I explain what I discovered let me give you an overview of the genome which you studied in the 1st unit. The genome (the haploid chromosomes and genes of an organism) is like a colony of genes and every gene has a fixed position or a permanent address on a specific chromosome. For example gene controlling pigmentation in corn seed is present on the short arm of chromosome # 9. However, there are some DNA segments which do not have fixed locations and they roam about the genome like gypsies. They are called transposable elements or jumping genes.

The exciting bit of my investigation was that the discovery of these transposable elements helped me in explaining the unusual speckled trait of corn seed.

In case of corn, a transposable element is composed of two components: Ds and Ac. Both are present on chromosome #9 where wild type gene C for pigment control is located. Ds can jump from one place to another by a conservative mechanism of transposition also called cut and paste transposition. Its (Ds) mobility is connected to the activity of another element Ac because Ac codes for an enzyme called transposase that starts transposition. As long as Ac continues to perform its normal activity (coding for the production of transposase) the element Ds moves from one place to another.

Now let me explain to you how the understanding of transposable elements helps in explaining the speckled phenotype of the corn seed. A transposable element causes mutation when it gets inserted into a gene by splitting it apart and thus the gene stops performing its normal function and becomes mutant. But in case of speckled corn seed something different happens



Suppose gene C is present on its specific location on chromosome # 9 and performing its function of coding for purple pigment, anthocyanin. This pigment is produced in chromoplast at organelle level. This normal gene activity will result in the purple corn seed coat. It is evident that the gene activity (molecular level) affects the activity of chromoplast (organelle level) which in turn has its impact on the phenotype of seed coat (Organ level)

Now, suppose that a transposable element (Ds with the help of Ac) jumps around and lands on the position occupied by gene C splitting it into two parts by inserting itself into the middle of the gene (see model 2). The result of this insertion is the conversion of gene C (wild type) into gene c (mutant). The Ds has switched off the normal activity of gene and it stops coding for anthocyanin. If Ds remains inserted into this gene it will cause a stable mutation and the result of this mutation will be a yellow corn seed coat. However, what happened with speckled seed was something different (see model 2). It was an unstable mutation because during the developmental stage, Ds by the help of Ac inserted itself into the gene C (wild type) and switched it off thus stopping it to code for anthocyanin thus converting it into gene c (mutant).It means that due to the change in gene activity chromoplast also stops its normal activity of producing purple pigment.. After that again AC coded for transposase which made DS jump out of gene c and resulted in the switching on the gene and it started coding for purple colour again. This switching on and off happened several times therefore every time when gene was switched off it contributed yellow patch to the seed and whenever it was switched on, it contributed purple patch on the seed. It means that as soon as gene (molecular) stops coding for pigment, chloroplast stops producing anthocyanin and thus the activity of chromoplast causes corn seed (organ level) to be yellow.

The phenomenon of transposition can cause stable and unstable mutation. The result of stable mutation will be yellow corn seed but unstable mutation will produce speckled corn seed. This is how the speckled corn seed, got its beautiful coat.

It is evident from the above description that the activity of Ac affects the mobility of Ds which has its effect on the gene activity and then gene influences the chromoplast function which has its impact on the seed coat.

The next page shows the levels as they apply to a corn seed. It will help you to visualise the levels. I hope this make understanding easier for you.

Barbra McClintock

Appendix B

Worksheets

(Scotland and Pakistan)

Unit 1

Things to Do
Ladders in Biology

Have you ever thought about biology in this way? There are many levels in biology - a bit like a ladder.
Look at the diagram at page 4 in your booklet.
In this set of tasks, you will be thinking about transposable elements

Working with a partner, see if you can answer the following questions quickly.
Go fast – you have about 15 minutes!

Your registration number ....

Can you remember some key ideas?

Task 1

For this activity, in your imagination, you have to descend down to the DNA and gene levels.

Find and write
(a) The collective term for transposable element ....
(b) Three types of transposable elements found in *bacteria*
1:................. 2: .... 3:...............
(c) Two types of transposable elements on the basis of mechanism of transposition
1: .... 2: ....
(d) Alternative names for the following
1: conservative transposition ....
2:............ Copy and paste mechanism

(e) A DNA sequence with fixed position and specific function is called.................. while a DNA segment with mobile nature is known as ....

(f) A coding region of DNA segment is known as...................... while the non-coding region is called ....

Task 2

For this task you have to stay at DNA and gene level in your thinking
(a) Encircle one of the following transposable elements which is different from the other three
(1) DS (2) Copia (3) LINE (4) SINE
Why do you find it different?
....
....

(b) DNA *transposon* and *retrotransposon* have similar impact in increasing the gene size.

However, they differ in having an impact on the overall size of DNA segment (genome size).Which one of them has the ability to increase the genome size?

....

Why does it do so?..

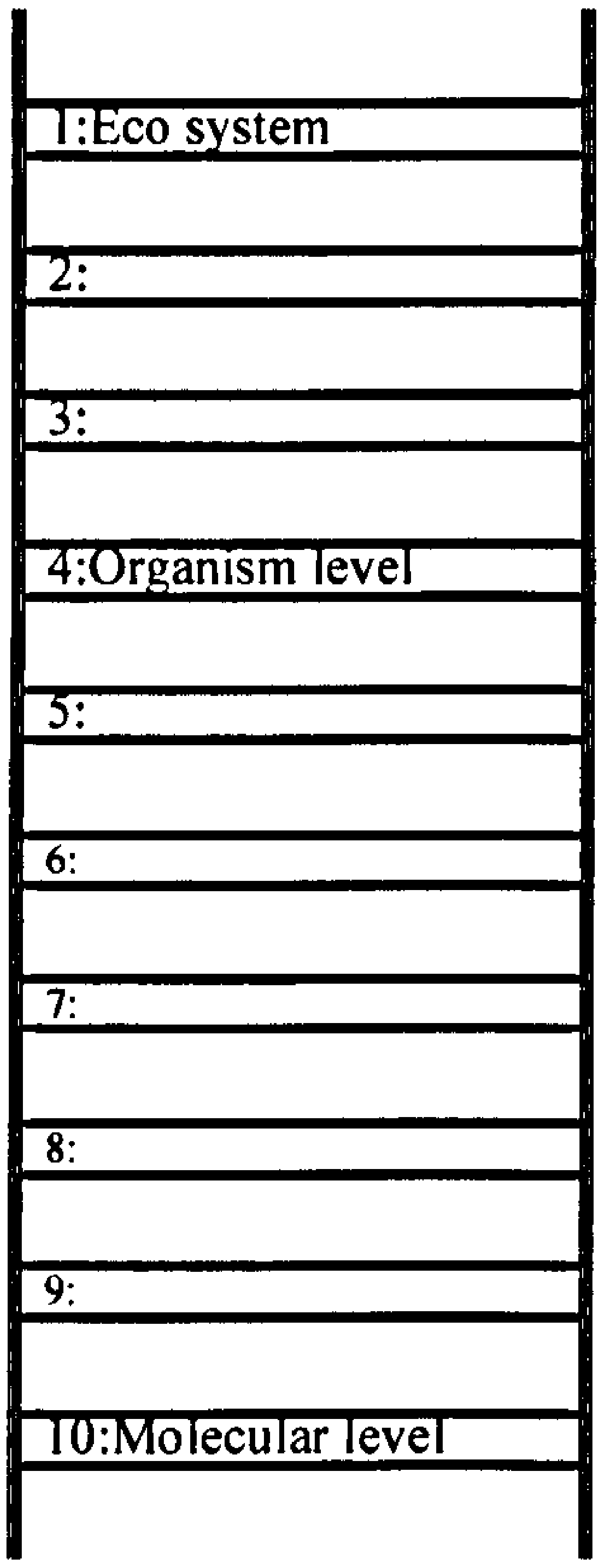
Task 3

For this activity you have to move up and down on the ladder. The biological world is composed of multiple layers that are linked together.

(a) Fill in the empty rungs in the given ladder.

(b) Think of the molecular levelGive the name of the enzyme, which makes the transposable element to jump?

....



(c) Each of the following belongs to one level.

Using the level numbers, show where each belongs.

Nature' Casanova ....
Bacteria ....
Ds and Copia element ....
A pack of wolves ....
Mitochondria ....
A piece of your bone ....
A garden pond ....

(d) Perhaps 'Nature's Casanova' is not quite the right name.
Suggest a better name: ....

(e) Use your imagination!!

Try and draw diagrams, which show the following

(1) Transposon (2) Insertion sequence(3) Cut and paste transposition(4) Copy and paste transposition

(*You can use the backside of this page for drawing)*

Work Sheet: Unit 2

Things to Do

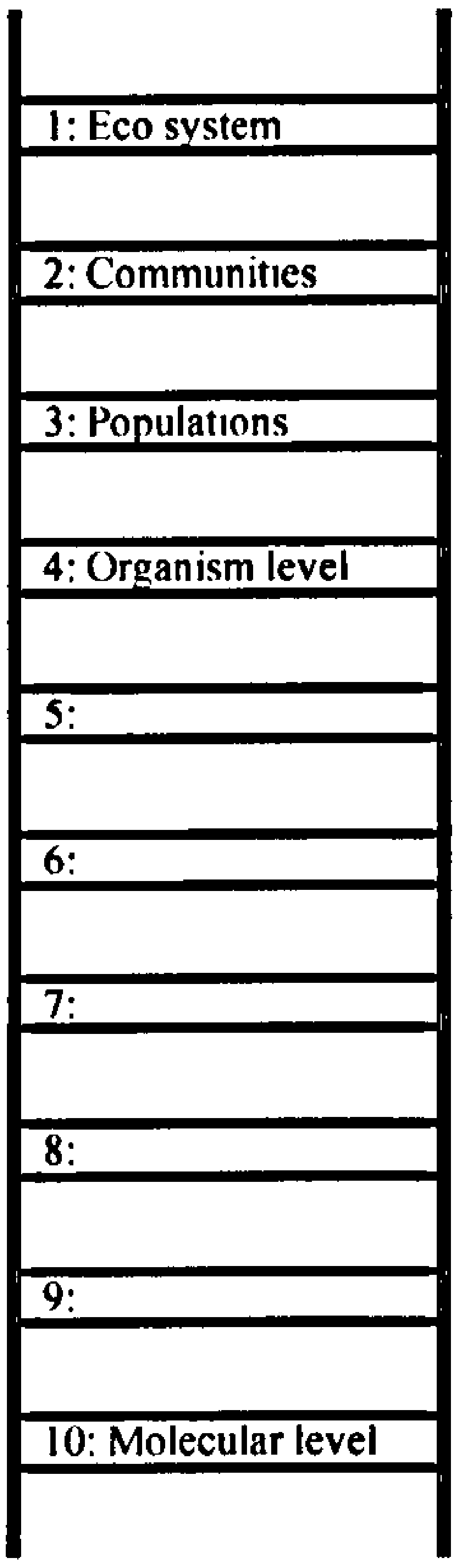
Linked Rungs in the Ladder In thinking about the corn seed, it is helpful to see the many levels in biology. Understanding at various levels often allows us to make sense of what is happening at the other levels. Look at the compact summary at page 4 in your booklet, which explains that things happening at one level may have influences at all levels.

Working with a partner, see if you can answer the following questions quickly.
Go fast – you have short time

Your registration number ....

Task 1

For this task you have to move on the ladder up and down
We consider the corn (maize) plant as an organism.
Fill in a description of the levels *in the empty spaces in the ladder keeping in view the corn seed.*



Task 2

Thinking of the speckled corn seed, fill in the details in level/component columns.
(Consult the compact summary given to you at page 4 in your booklet)

Level	*Components of each level*
....	Corn plant
Organ level	....
.... level	Multitudes of cells identical in every respect.
.... level	A cell with its organelles.
....	Chromosome number .... Arm of chromosome .... (Short or long arm)
....	Coding region of DNA segment ....; Gene (responsible for pigmentation) .... Two components of transposable element .... and .... (Names of two components)
....	Enzyme produced by transposable element .... (Name of the enzyme)

Task 3

For this task you have to stay at the gene level to observe the consequences of one change at the same level.

When a transposable element **Ds** jumps into wild type gene ***C***, it not only affects the phenotype of the seed. Apart from this observable change, many changes happen at microscopic level.

Below are shown two DNA segments:

Segment '1' carries a gene '***C***' responsible for purple pigment in corn seed.
Segment '2' shows that the gene '***C***' is invaded by '**Ds**', a transposable element.

Segment 1

A	B	C	D	E	**Ds**	F

Segment 2

A	B	*c* *Ds* *c*	D	E	F

Work *with your partner* and try to figure out the answers:

(1) What change is observed in the *size* of gene ***C*** after the insertion of Ds?
(a) Normal (b) bigger (c) smaller

(2) What change is observed in the *size* of DNA segment?
(a) Normal (b) bigger (c) smaller

(3) Think and write what change will you observe in gene activity?
....

Now suppose *Transposable element* Ds jumps out of gene "*c*".

(4) What change is observed in the *size* of gene ***c*** after Ds jumps out of it?
(a) Normal (b) bigger (c) smaller

(5) What change is observed in the *size* of DNA segment?
(a) Normal (b) bigger (c) smaller

(6) Think and write what change will you observe in gene activity?
....

Stay at the gene level.

Think about Ds (transposable element) and then decide which one is true and false.

	True	*False*
(1) It increases the size of the gene responsible for purple pigment in corn seed	☐	☐
(2) It can increase the size of the DNA segment	☐	☐
(3) Ds is a retrotransposon	☐	☐

Think about the organ level.
What type of effect would you expect to see on the **phenotype of corn seed** as a result of the following?

(1) Stable gene mutation ....
(2) Unstable gene mutation ....
(3) Normal gene activity ....

Now think about different levels

(1) What information do you need from the following levels to show the presence of a *transposable element* in a gene responsible for pigmenataion and causing a ***stable mutation*** in case of corn seed?

Organlevel ....
Genelevel ....
Molecularlevel ....

(2) What information do you need from the following levels to show that a mutant gene (*c*) is present and causing an ***unstable mutation*** in corn seed?

Organ level..............Gene level.................Molecularl evel...............

Task 4

For this task, try to move up and down on the level ladder to pull all the components and levels together.

Discuss how you might draw a diagram (or a series of diagrams) for a new biology textbook suitable for the Higher Grade syllabus at school. The diagram is to show the phenomena of transposition resulting in ***speckled corn seed***.

***Remember*:**
Include all the relevant components from all the levels of biological organisation.
Do not forget to show the levels of organisation involved in the process of transposition.
The learners are aged 16-17, with a background only of Standard Grade Biology!Look at the compact summary (at page 4 in your booklet) for getting idea for this drawing.

Draw the diagram below (a joint effort!)
(Create your own diagram. Do not copy the one on page 4)

Unit 3
Things To Do
Vertical links in The Wrinkled Pea

The nature of a wrinkled pea seed can be explained from different levels of biological organisation.

This means that all the levels are linked, affecting one another directly or

***Working with a partner*, see if you can answer the following questions quickly.**
Go fast – you have short time
Your registration number ....

Task 1

You have to think about the ***molecular level.***
Suppose you have chemical samples from two molecular levels of two seeds, round seed and wrinkled pea seed.

(a) Discuss with your neighbour the differences you find between the two samples in terms of the presence of enzyme/s.
Round peas seed ....
Wrinkled pea seed............................

(b) The presence of two specific enzymes at the molecular level will indicate the presence of transposable element. Name the two enzymes.
Enzyme # 1 ....
Enzyme #2 ....

Task 2

For this task, you are on the ***molecular level*** but you have to move towards the upper levels as well.
Suppose you are given information about a pea seed from the *molecular level* that it contains an *inactive SBE-I (enzyme).*

What will you predict about the levels above the molecular level?

(a)**Gene level:** Genotype of the seed: .... Gene size: ....
Is transposable element present in the gene? Yes No
(b)**Cellular level:** Which starch will be synthesised: ....
(c)**Organ level:** Phenotype of the seed ....

Suppose you are given information about a pea seed from the *cellular level* that it has ability to synthesise *amylopectin* (branching starch) what will you predict about the following levels

(a)**Organlevel:** Phenotype of the seed:...

(b)**Gene level:**

Genotype of the seed: .... Gene size ....

Is transposable element present in the gene? Yes No

(c)**Molecularlevel:** Which enzyme(s) is present? ....

Task 3

(a) Think of pea seed

(1) You are told that a gene responsible for pea seed shape has been invaded by a transposable element. What information do you need from the following levels to support the presence of a transposable element?

Organ level ....
Cellular level ....
Gene level ....
Molecular level ....

(2) If a transposable element gets inserted into a gene responsible for pea seed shape, what ***changes*** do you expect at the gene level?

....

(3) You are given a *wrinkled pea seed* and you have to explain why it is so. What information you need from the following levels for your explanation.

Organ level ....
Cellular level ....
Gene level ....
Molecular level ....

(b) Here are the components from different levels of biological organisation responsible for the wrinkled and smooth pea seed.

All cells have amylopectin	Amylopectin 2	Gene *w* 3	Transposable element 4
Inactive SBE I 5	Smooth pea seed 6	All cells have amylose 7	Active SBE- I 8
Transposase 9	Bigger gene 10	Pea plant 11	Wrinkled pea seed 12
Gene *W* 13	Smaller gene 14	Pea pod 15	Amylose 16

Use the number of the boxes to fill in the ***column B.***
(There may be more than one number for each level).

Column A **Name of the level**	**Column B** **Name of the component**
1: Organism level	
2: Organ level	
3: Tissue level	
4: Cellular level	
5: Chromosomal level	
6: DNA and gene level	
7: Molecular level	

Task 4

Your granny notices the existence of round and wrinkled peas and, knowing you are studying biology, asks you to explain why it happens.

Discuss how you might approach this so that she can understand that what happens at one level can affect what happens at another. Your granny is very intelligent but knows no biology!

Draw a diagram (or a series of diagram) to help her to understand the secret of wrinkled pea seed. Do not forget to show different levels and components from these levels.
(Create your own diagram. Do not copy the one on page 4)

Oral revision sheet
Unit 1

Talk to you partner about the following

(Part 1)

- Which level of biological organisation has been described in detail in this section?
- Do you find other levels mentioned in this section?
- Definition of the following terms: Gene, genome, junk DNA
- At sub cellular level three different types of DNA segments have been mentioned in this section, what are they?
- Why all the human genome is not functional.
- Most of the structural components of the genome from the sub cellular levels have been described in the first section of your booklet, do you find an activity or process or any phenomena involving these components?
- Name three phenomena which bring about change in gene and genome?
- In this section two views about the genome are presented how do they differ from each other?
- Definition of the following: Transposable element, Transposition
- Why transposable elements are called agents of mutation.
- Why human genome is so big?
- In which plant first transposable element was first discovered?

(Part 2)

- Names of the transposable elements found in bacteria.
- What are the names of the two parts of insertion sequence
- What are the common features between IS and transposons
- How do the main bodies of IS and transposon differ from each other?
- What does transposable elements do which change the structure and function of gene?
- What is the function of transposase gene?
- What is an antibiotic?

(Part 3)

- What are the alternative names for conservative and replicative mechanism of transposition?
- What is the difference between both two types of mechanisms?
- How do both mechanisms differ in having their impact on genome size?
- What is the similarity between two mechanisms?

Unit 1
Things to Do

Zooming in and zooming out in Biology

For the following tasks you have to stay at sub cellular level in your thinking

(1) There are two segments of DNA, **segment A** and **segment B**. In both segments the transposable elements are present. Transposition occurs in both but only segment B becomes longer and heavier as compared to segment A, explain the reason (write it down). And show your answer by drawing a diagram

(2) Suppose in a bacterial genome if a DNA segment has a transposable element and this element jumps into another gene (say gene E) by replicative method of transposition and then moves again but this time into non functional area of the DNA segment. What change you will see in this specific gene (E) and at the whole genome level.

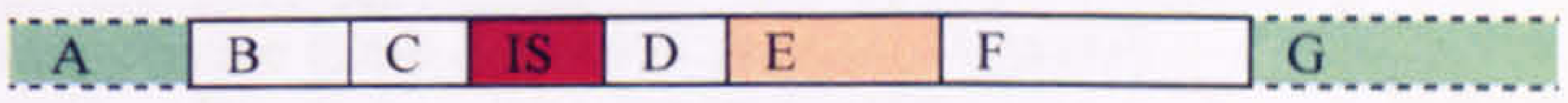
(3) You are told that two segments of DNA having the same length but have different transposable elements. One segment is having DS while the other is having LINE. Transposotion occurs in both the segments .What will you tell about the length of both segments after the phenomena of transposition? Explain it

(4) Consider the following two cases and give reasons

(a) Size of a gene in a DNA segment has increased and the DNA segment has become has become bigger as well.

(b) Size of a gene in a DNA segment has increased but the DNA segment has the same length.

(5) Suppose in following bacterial DNA segment, there is one ***Insertion sequence*** (a transposable element).



The insertion sequence jumped into a ***gene E*** conservative transposition. What changes (structural and functional) you will observe in gene E and the respective DNA segment.

(6) Zoom in and zoom out in your imagination and put the following elements into levels to which they belong to

Name of the elements	**Name of the level**
Skin of your hand	… … … … … … … … …
sparrow	… … … … … … … … …
Transposase (enzyme)	… … … … … … … … …
Heart	… … … … … … … … …
Human genome	… … … … … … … … …
Bacteria	… … … … … … … … …
A garden pond	… … … … … … … … …
Paramecium	… … … … … … … … …
Mitochondria	… … … … … … … … …
A group of lions	… … … … … … … … …

(7) Suppose you have 6 bacterial samples (given in the next table) and you also have information about their genome. You have to kill these bacteria and for killing them you only have the following antibiotics

(a) Penicillin (b) Tetracycline (c) Erythromycin

(a) Which of the above given antibiotics can be used to kill each category of bacteria in the following table?

(Write down the names of the antibiotics in the column which you think will kill the bacteria.)

(b) What do you think is there any bacteria in the above mentioned categories for which a new antibiotic is needed to kill it?

If you see a need, explain why?

(c) How do you see the levels of biological organisation differ in multicellular and unicellular organism?

Bacteria	**Information from genome**	**Medicine needed for killing bacteria**
A	Trnasposase gene only	
B	Transposase gene & Genes resistant against • Tetracycline	
C	Transposase gene & Genes resistant against • Penicillin and Tetracycline	
D	Transposase gene & Genes resistant against • Erythromycin, Penicillin, and tetracycline	
E	Transposase gene & Genes resistant against • Erythromycin and Penicillin	Tetracycline
F	Transposase gene & Gene resistant against • Penicillin	

Oral Revision sheet
Unit 2

Talk to you partner about the following

1: Name different type of phenotypes of corn seed?

2: On which chromosome, gene for controlling pigmentation is present?

3: Which one of the following is mutant and why?

Purple corn seed, yellow corn seed, speckled corn seed

4: Who discovered the first transposable element in corn seed?

5: What is the composition of transposable element found in the corn seed genome?

6: What is the location of Ds on the chromosome in case of speckled corn seed?

7: What does Ds need to jump or move?

8: Where does Ds get support to jump or to move?

9: What do you understand by the term 'stable mutation'?

10: What do you mean by the term 'unstable mutation'?

11: What is the difference between stable and unstable mutation?

Work Sheet 2

Zooming in and zooming out in Biology

In thinking about the corn seed, it is helpful to see the many levels in biology. Understanding at various levels often allows us to make sense of what is happening at the other levels, which explains that things happening at one level may have influences at other levels

Your Name …………………

Your Roll number …………………

Task 1

Thinking of the speckled corn seed, write down the components and processes from the genome level.

Level	**Components of level**	**Processes/ mechanisms**
Molecular level …………	…………	………………………………………………………

Task 2

For this task you have to stay at the gene level to observe the consequences of one change at the same level and the other levels.

When a transposable element **Ds** jumps into a wild type gene *C*, it not only affects the phenotype of the seed. Apart from this observable change, many changes happen at other level as well.

✧ *Following* Segment shows that a gene responsible for pigmentation in corn seed carries 'Ds', a transposable element permanently in it, What will you tell about the following

Ac	B	*c* *Ds* *c*	D	E	F

(1) What do you expect about the phenotype of corn seed? ……………………………
(2) What is your conclusion about the gene size?………………………………
(3) What do you conclude about gene activity?……………………………………………
(4) What changes in the activity of chromoplast?…………………………………………
(5) What Kind of mutation do you think it is? ……………………………………………
(6) What type of mechanism of transposition is involved? ………………………………
(7) The enzyme involved? ……………………………………………

You are told that a DNA Segment carries a wild type gene '*C*' in case of corn seed. What will you tell about the following?

(1) Phenotype (organ level)
(2) Gene size (molecular level)
(3) Gene activity (molecular level)
(4) Pigment production (organelle)

Stay zoomed at the gene level.

Think about Ds (transposable element) and then decide which one is true and false.

(1) It increases the size of the gene responsible for pigment in corn seed coat ☐ ☐
(2) It can increase the size of the DNA segment ☐ ☐
(3) Wild type gene for pigmentation production is smaller in size than the mutant gene ☐ ☐
(4) The size of the gene becomes larger after DS jumps out of the gene ☐ ☐

Think about the <u>phenomena at the molecular level</u> and its effects on organ level.

What type of effect would you expect to see on the **phenotype of corn seed** as a result of the following phenomena?

Stable gene mutation ………………..
Unstable gene mutation ……………… .
Normal gene activity ………………

Now think about different levels

(1) What information do you need from all the levels involved to prove <u>normal gene activity</u> in case of corn seed coat?

Levels	**information (components, chemical, processes)**
1……………………..	…………………………………………………………………
2……………………..	…………………………………………………………………
3……………………..	…………………………………………………………………

(2) What information do you need from all the levels involved to show that ***unstable mutation*** is occurring in case of corn seed coat?

Levels	**information (components, chemical, processes)**
1……………………..	…………………………………………………………………
2……………………..	…………………………………………………………………
3……………………..	…………………………………………………………………

✧ *You are told that a gene responsible for pigmentation in case of corn seed coat has stopped coding for anthocynanin. What information you need to support this statement from other levels (organ, , organelle& molecular levels)*

<u>Levels</u>	**<u>information (components, chemical, processes)</u>**
1........................	....
2........................	....
3........................	....

(3) If a gene responsible for pigmentation is switched off. <u>What other activities will be stopped and what will be their effects?</u>

....

....

Task 4: For this task, try to zoom in and out to pull all the components and levels together.

Draw a diagram (or a series of diagrams) to show the phenomena of transposition resulting in ***<u>speckled corn seed</u>***.

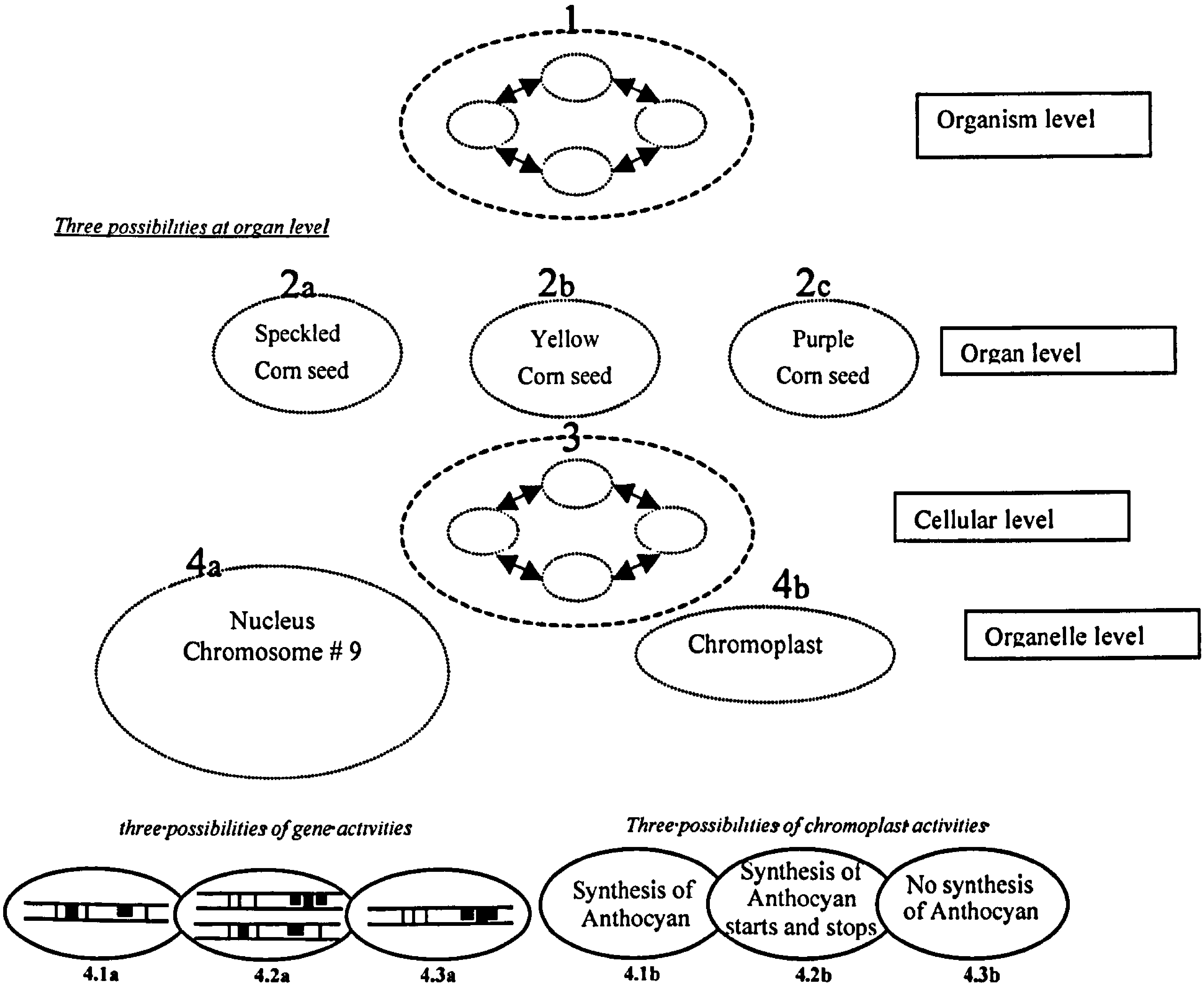
Remember: Do not forget to show the levels of organisation and all the relevant components and processes from all the levels of biological organisation involved in the process of transposition.

***Draw the diagram below** (Create your own diagram. Do not copy from the given one)*

Model Based Work Sheet

Your name .... Your roll number..

Look at the model and answers the following questions



(1) Which phenomenon is being represented in 4.1a .... 4.2a .... 4.3a ....

(2) Match components with 2b from 4a and 4b. .... & ....

(3) In which of the three possible phenomena at 4a, the enzyme trnaposase is completely absent? ....

(4) In which of the three possible phenomena at 4a, the enzyme transposase is being produced without ant interruption? ....

(5) At organelle level the chromoplast activity at 4.3b is linked to which phenmomena at 4 a? ....

(6) Which possible activities from 4a and 4b are linked to 2b? .... & ....

(7) What does 4.2b tell you about the gene activity? ....

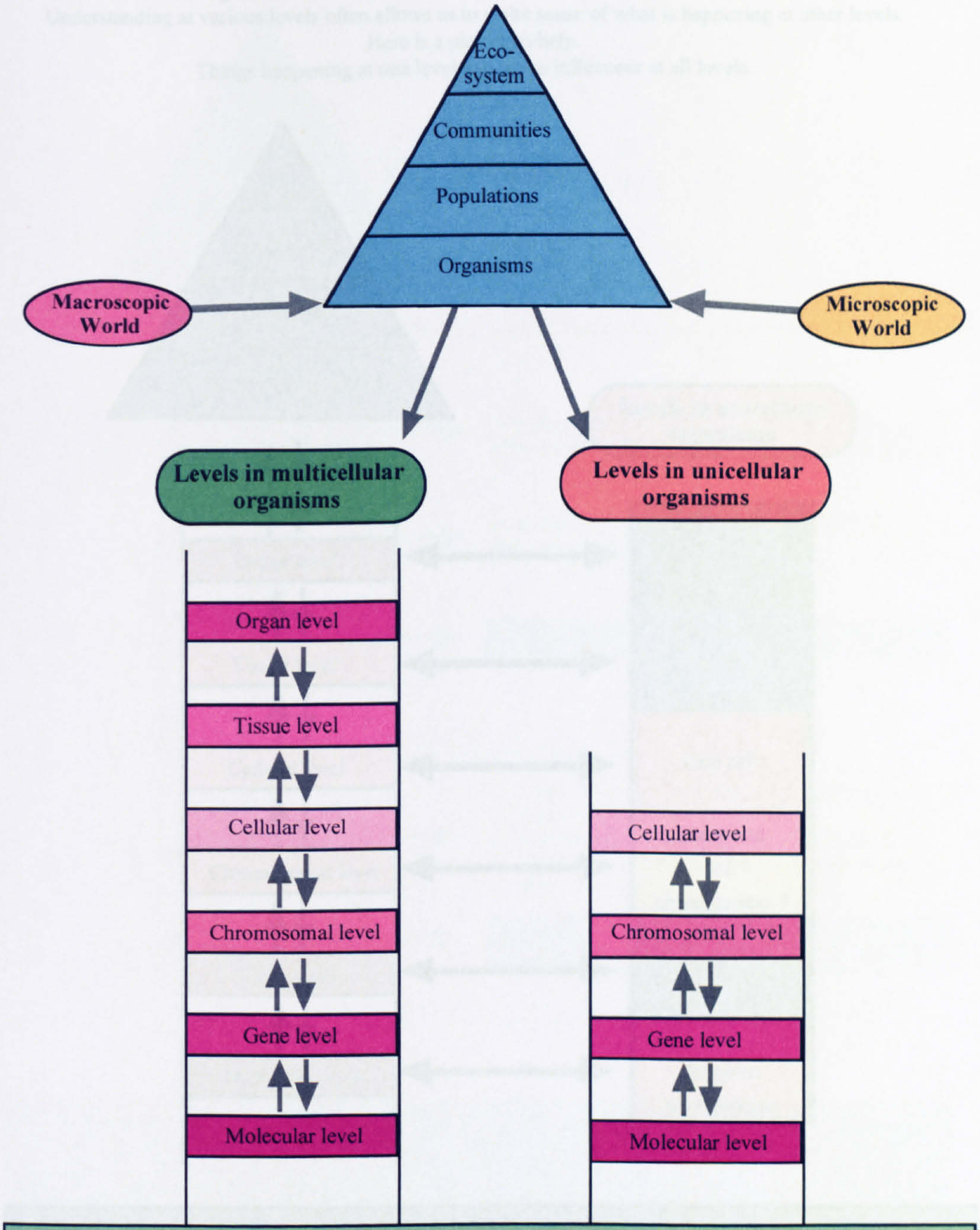
(8) What link do you see between the two components (nucleus and chromoplast) of the organelle level?

Appendix C

System-based Models

(Scotland and Pakistan)

Levels of Biological Organisation

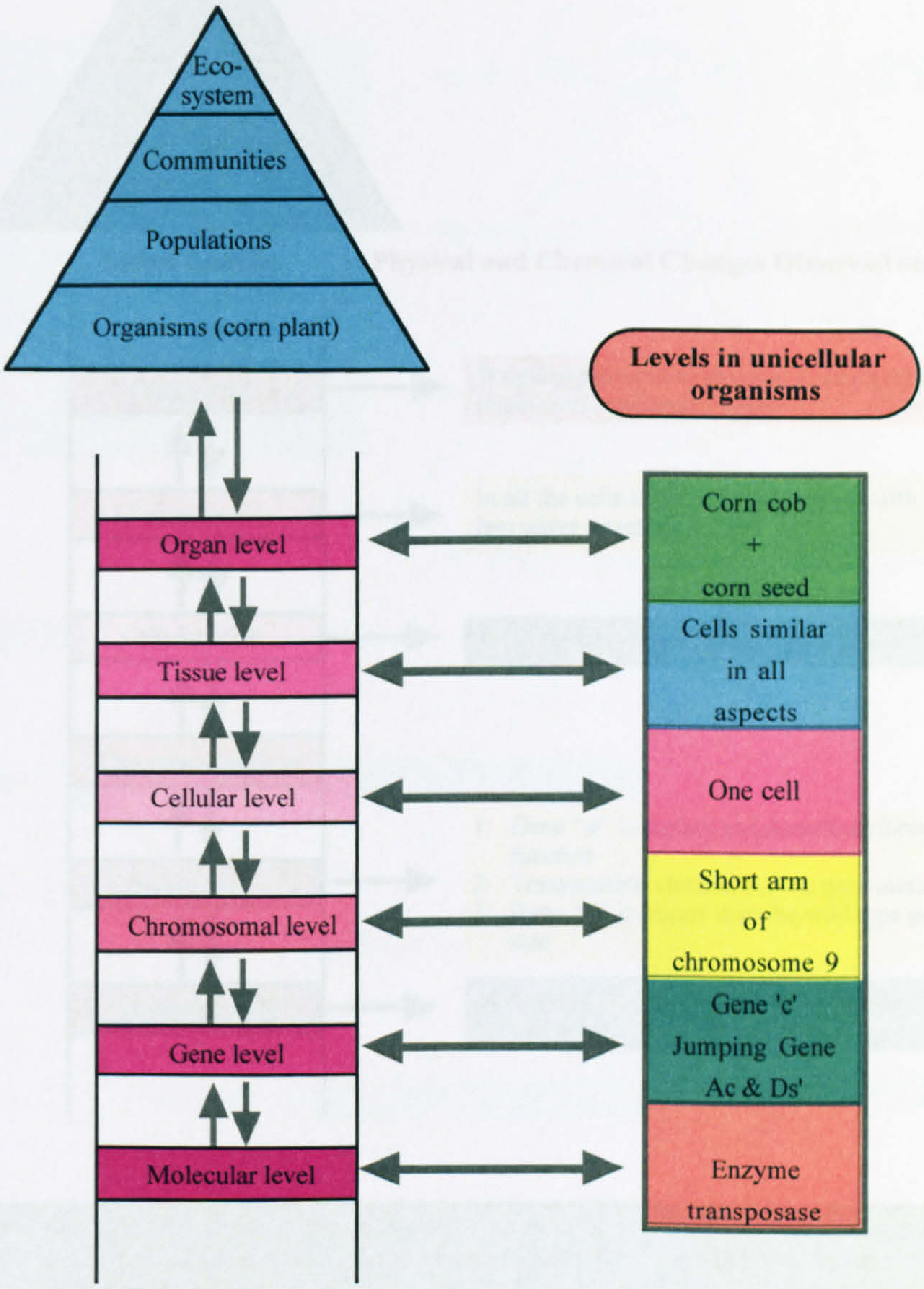


Biology deals with the organisms belonging to the microscopic and macroscopic world. **Organisms** of the same species make a **population**, different populations interact and form a **community** and then communities together constitute an **ecosystem**. Each organism, multicellular and unicellular, is composed of different levels of complexity. These levels include *organ, tissue, cellular, chromosomal, gene and molecular levels.*

Now Try Some Activities with Your Partner
Have fun!!

Components of Levels - Transposition Causing Speckled Corn Seed

In thinking about the corn seed, it is helpful to see the many levels in biology.
Understanding at various levels often allows us to make sense of what is happening at other levels.
Here is a picture to help.
Things happening at one level may have influences at all levels.



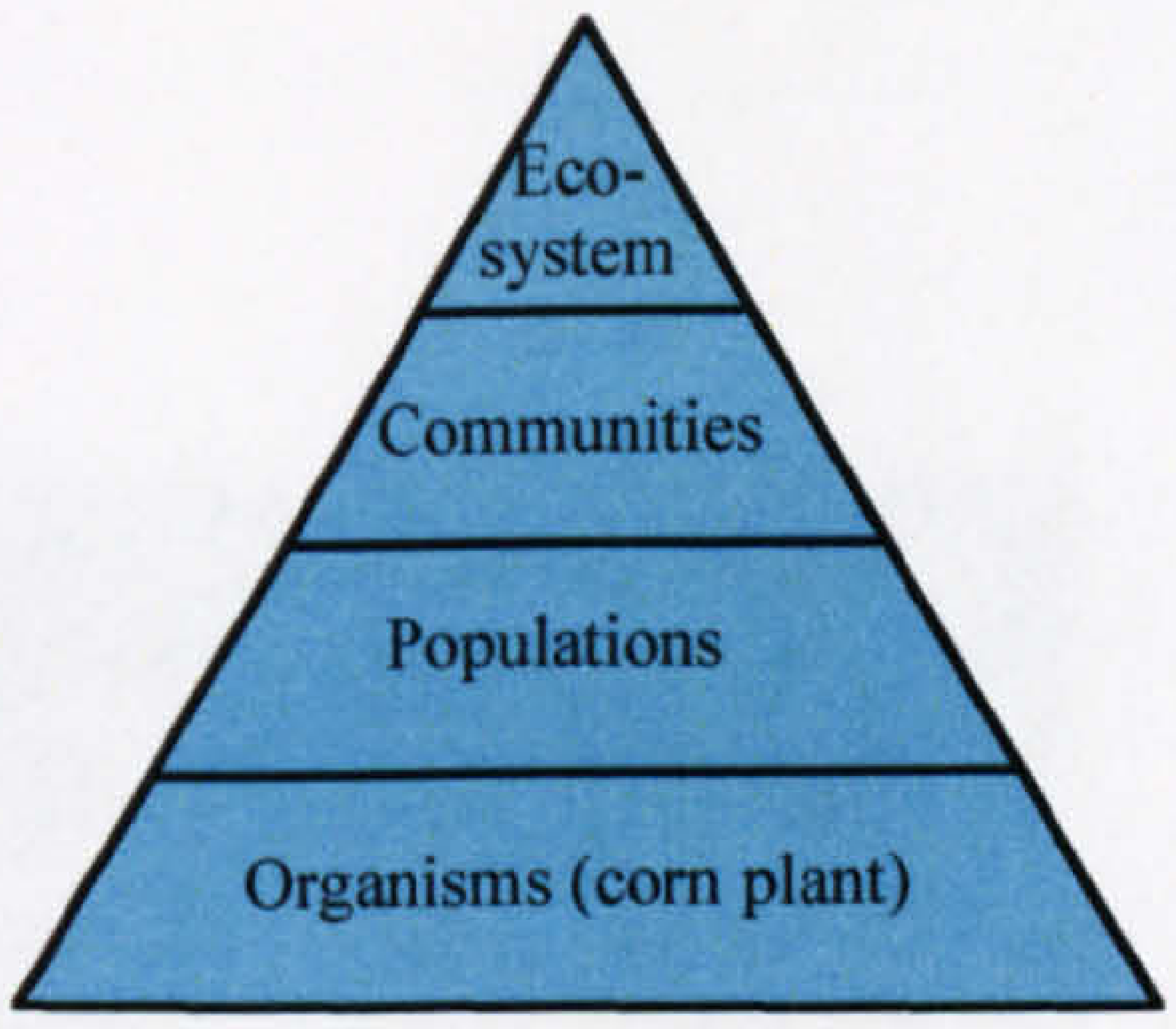
This shows a corn plant (organism) as a system of multiple layers or levels.

The level ladder on the left hand side shows the different levels in a corn plant. The right hand side shows the components for each level.

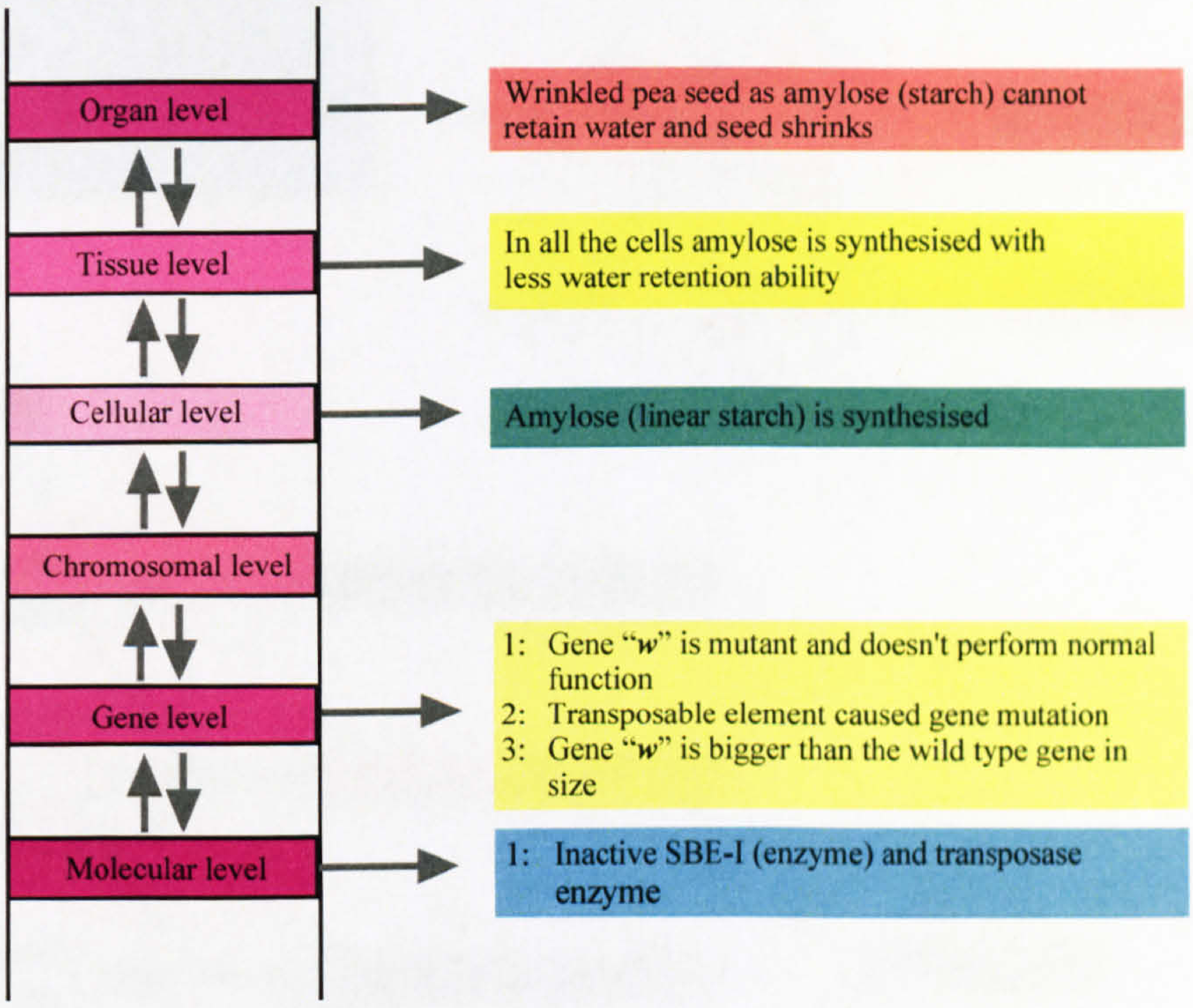
A change at organism level can be traced down to the molecular level and the consequences of the changes at molecular level can be observed at the organ or organism level.

Now Try Some Activities with Your Partner
Have fun!!

Components and Changes at each Level in Wrinkled Pea Seed.



Level Ladder **Physical and Chemical Changes Observed on the Levels**



Wrinkled pea seed as amylose (starch) cannot retain water and seed shrinks

In all the cells amylose is synthesised with less water retention ability

Amylose (linear starch) is synthesised

1: Gene "*w*" is mutant and doesn't perform normal function
2: Transposable element caused gene mutation
3: Gene "*w*" is bigger than the wild type gene in size

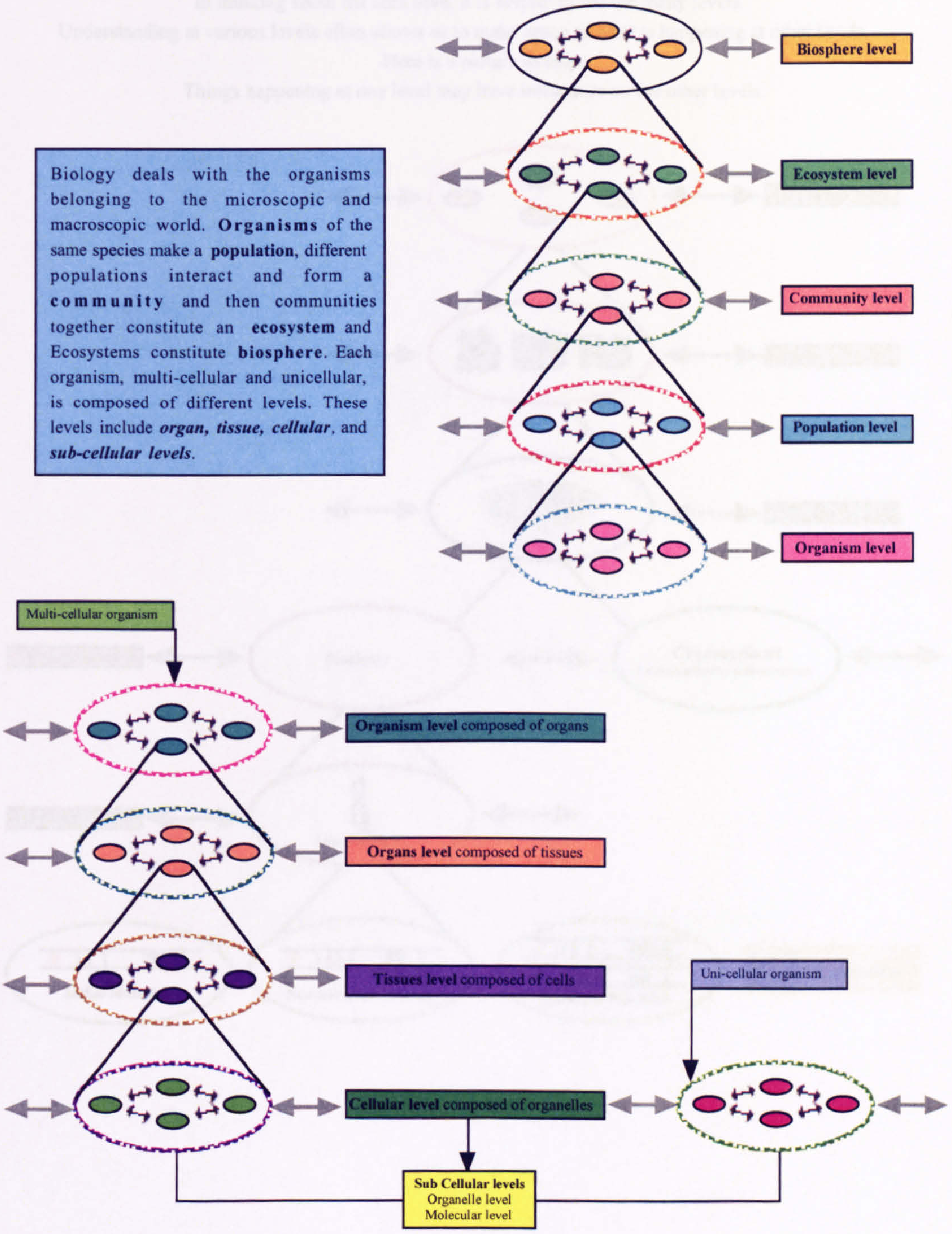
1: Inactive SBE-I (enzyme) and transposase enzyme

The nature of the wrinkled pea seed can be explained from different levels of biological organisation. For example if you have information from the molecular level you can predict changes on the gene and organ level (the genotype and phenotype of the seed). Similarly if you have information from the gene level (type and size of the gene), you can explain expected changes at the molecular and organ level. It means that all the levels are linked vertically, affecting one another directly or indirectly.

Now Try Some Activities with Your Partner
Have fun!!

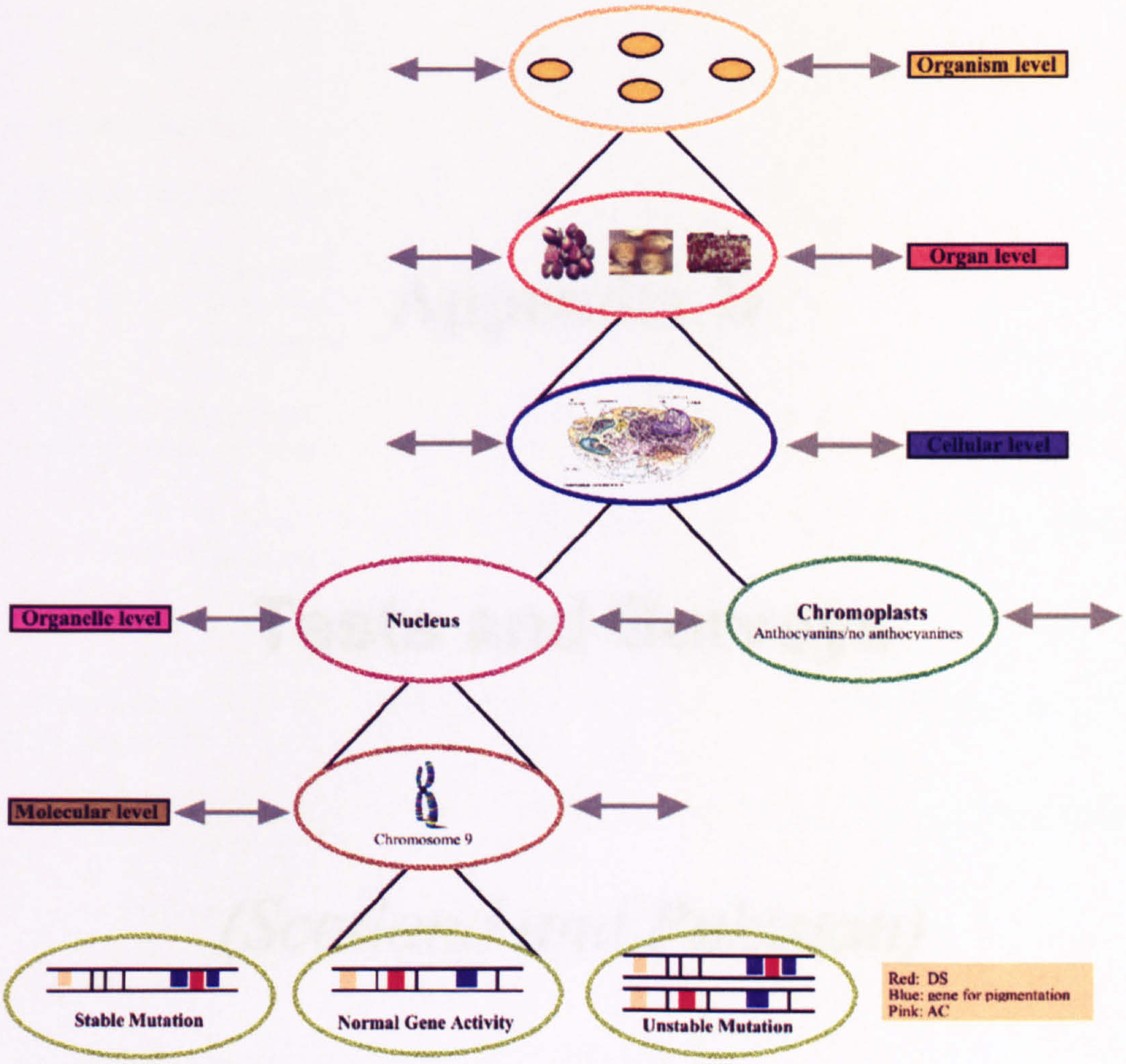
Systems-based Model

Biology deals with the organisms belonging to the microscopic and macroscopic world. **Organisms** of the same species make a **population**, different populations interact and form a **community** and then communities together constitute an **ecosystem** and Ecosystems constitute **biosphere**. Each organism, multi-cellular and unicellular, is composed of different levels. These levels include ***organ, tissue, cellular***, and ***sub-cellular levels***.



Corn Seed Coat and Transposition

In thinking about the corn seed, it is helpful to see the many levels.
Understanding at various levels often allows us to make sense of what is happening at other levels.
Here is a picture to help.
Things happening at one level may have influences on the other levels.



Appendix D

Tests and Surveys

(Scotland and Pakistan)

Semi-Structured Interview Schedule

For University Biology Teachers.

Details of the respondent

- Name:
- Teaching experience:
- Sex:

A. Systems Biology

1. What do you understand about this new emerging field of systems biology?

    - What is the driving force behind it?
    - Why there is not consensus about its definition?
    - How systems biology differs from existing biology?

2. The two terms reductionism/holism are often used in literature with reference to research in biology. What are your views on these terms in relation to biology research?

    - Is the term reductionism appropriate or misleading for biological research at molecular level?
    - Is systems biology a holistic approach?
    - Is it another extreme like reductionism?

3. When biologists talk about system, there is a need to put a boundary around the systems being examined?

    - What do you think the boundary in systems biology is? cell ,organ, organism or any other
    - Is it appropriate?
    - Why do you think this?
    - Is it very much focused on human being?

4. In your view what will be the impact of systems biology
    - On life in general
    - On Research
    - On Education?

B. Systems thinking

1. What do you understand by the term systems thinking?
    - Is it new?
    - Instinctive / learnt?
    - Is it a high order skill or a general ability?

C. Teaching and Learning

1. Is biology a difficult subject to teach and learn?
   - If yes, what makes it difficult to understand?
   - If no, why?

2. Genetics is considered the most difficult area in biology. Do you find it hard to teach?
   - If yes, why is it so?
   - If No, what is your teaching approach/how do you teach?

3. Which topics in Genetics you find difficult to teach in terms of students' understanding?

4. In general what are your views on students understanding of biology concepts when they start undergraduate courses in biology?

5. How well they see interconnectedness or they have fragment knowledge?

6. In general how is biology taught at university level?
   - Emphasis on content
   - Emphasis on making links and connections

7. In literature it is being reported that teaching is mechanistic .What is your opinion?
   - Do you find biology teaching mechanistic?
   - Yes why?
   - No why?

8. In what aspect biology teaching is needed to be improved?
   - Curriculum
   - Teaching method
   - Students attitude towards biology

Biology Difficulty Survey

Faculty of Education, Department of Curricular Studies

University of Strathclyde

This survey is designed to explore the core areas and the topics in 1st year biology curriculum which are considered difficult. You have been selected because you have studied it in your 1st year and you are in a position to say what was difficult from your point of view and why it was so. Feel free to select the boxes to express your opinion because there are no right and wrong answers. Your participation will be appreciated but if you do not want to take part in it then it is ok. However, your responses are of great value because they will help us in finding out the difficult areas and topics in biology curriculum to make them easier to teach and learn.

I thank you, if you take part to fill in the questionnaire.

Shagufta Shafqat Chandi

PhD Candidate

Faculty of Education

Jordan hill Campus

Biology Difficulty Survey

Faculty of Education, Department of Curricular Studies
University of Strathclyde

Please fill in the following details about yourself.

Name (optional): ....

Gender: ....

Age: ....

Course: ....

From the following core areas please tick the two which you felt were more difficult.

1: Cellular Structure and Function ☐

2: Genetics and Molecular Biology ☐

3: Microbial and Plant Bioscience ☐

4: Animal Bioscience ☐

After selecting two areas please go to the relevant page, read it carefully and tick the relevant boxes. Please note the following direction

If you have selected the **first option** then go to page number 3-4

If you have selected the **second option** then go to page number 5

If you have selected the **third option** then go to page number 6

If you have selected the **fourth option** then go to page number 7

1. Cellular Structure and Function –Difficulty Survey-

This survey is designed to explore the difficulties in this course.
Your participation will help us to improve learning and teaching.

Easy	I understood the topic first time	1st Box
Moderate	I found it difficult but I understand it now	2nd Box
Difficult	I still do not understand it	3^{rd} Box

If you wish, you may write comment about difficulties in the space provided

Please tick a box to show how you found the following topics in biology

	E	*M*	*D*
Basic Chemistry for Bioscience			
Carbohydrates	☐	☐	☐
Lipids	☐	☐	☐
Amino acids and Proteins	☐	☐	☐
Nucleic acids and Proteins	☐	☐	☐
Basic Concepts of metabolism			
Glucose oxidation	☐	☐	☐
ATP synthesis and Function	☐	☐	☐
Photosynthesis	☐	☐	☐
Introduction to cell theoy			
Size of Cells; Looking at cells	☐	☐	☐
Prokaryotic and Eukaryotic Cells	☐	☐	☐
Membrane Structure	☐	☐	☐
Transport Across Membranes	☐	☐	☐
Organelles and their functions 1:			
Nucleus:	☐	☐	☐
Ribosome	☐	☐	☐
Endoplasmic reticulum	☐	☐	☐
Organelles and their functions 2:			
Golgi	☐	☐	☐
Lysosmoes:	☐	☐	☐
Vacuoles:	☐	☐	☐
Endomembrane system:	☐	☐	☐
Organelles and their functions 3:			
Mitochondria:	☐	☐	☐
Chloroplasts:	☐	☐	☐
Peroxisomes:	☐	☐	☐
The Cytoskeleton	☐	☐	☐

2. Genetics and Molecular Biology- Difficulty Survey

This survey is designed to explore the difficulties in this course.
Your participation will help us to improve learning and teaching.

Easy	**(E)**	I understood the topic first time	1st Box
Moderate	**(M)**	I found it difficult but I understand it now	2nd Box
Difficult	**(D)**	I still do not understand it	3rd Box

If you wish, you may write comment about difficulties in the space provided

Please tick a box to show how you found the following topics in biology

	E	**M**	**D**
Strand A Classical Genetics and the Human Experience	☐	☐	☐
Classical genes and their inheritance	☐	☐	☐
Genes, cells and chromosomes	☐	☐	☐
Evolution, gene shuffling and humans	☐	☐	☐
Problem solving: use of the Punnett square	☐	☐	☐
Chromosomes, DNA and jumping genes	☐	☐	☐
Implication of genetics for human health	☐	☐	☐
Mapping genes in humans and gene interactions	☐	☐	☐
Problem solving: Examples of genetic mapping and epistasis	☐	☐	☐
Strand B Molecular biology and molecular genetics	☐	☐	☐
DNA: The Genetic code and its role as an Information base	☐	☐	☐
The chemical structure and replication of DNA	☐	☐	☐
Mutation and DNA repair	☐	☐	☐

3. Microbial and Plant Bioscience-difficulty survey

This survey is designed to explore the difficulties in this course.
Your participation will help us to improve learning and teaching.

Easy	**(E)**	I understood the topic first time	1st Box
Moderate	**(M)**	I found it difficult but I understand it now	2nd Box
Difficult	**(D)**	I still do not understand it	3^{rd} Box

If you wish, you may write comment about difficulties in the space provided

Please tick a box to show how you found the following topics in biology

	E	*M*	*D*
The microbial world	☐	☐	☐
Microbial growth, nutrition and metabolism	☐	☐	☐
The prokaryotic microbes	☐	☐	☐
Archaebacteria and viruses	☐	☐	☐
Eukaryotic microbes	☐	☐	☐
Microbes are of use to mankind	☐	☐	☐
Microbes and diseases	☐	☐	☐
Plants: their importance: classification	☐	☐	☐
Plant cells and tissues: plant structure	☐	☐	☐
Plant growth and reproduction	☐	☐	☐
Plant growth and reproduction:			
Crop Biotechnology- feeding the world?	☐	☐	☐
Plants and energy: photosynthesis	☐	☐	☐
Plants and water: osmosis: transpiration	☐	☐	☐
Plants and the soil: N as a plant nutrient	☐	☐	☐
Plant signals and communication	☐	☐	☐
Plant biotechnology:	☐	☐	☐

4. Animal Bioscience -Difficulty survey

This survey is designed to explore the difficulties in this course.
Your participation will help us to improve learning and teaching.

Easy	I understood the topic first time	1st Box
Moderate	I found it difficult but I understand it now	2nd Box
Difficult	I still do not understand it	3rd Box

If you wish, you may write comment about difficulties in the space

Please tick a box to show how you found the following topics in biology

	E	*M*	*D*
The Metazoa: Origin and Organisation	☐	☐	☐
The Metazoa: Vertebrate Organisation	☐	☐	☐
Animal Cells, tissues and Organs	☐	☐	☐
Human nutrition and elementary canal	☐	☐	☐
Human gaseous Exchange and Respiration	☐	☐	☐
Cardio- vascular system	☐	☐	☐
Salt balance, Osmoregulation and Excretion	☐	☐	☐
Excretion and the human kidney	☐	☐	☐
Neural communication and control	☐	☐	☐
Chemical messengers in Vertebrates	☐	☐	☐
Control by hormones	☐	☐	☐
Systems of Immunity	☐	☐	☐
The vertebrate Immune system	☐	☐	☐
Neurons and the Vertebrate Nervous system	☐	☐	☐
Skeleton and Muscles	☐	☐	☐
Human Reproduction	☐	☐	☐

University of Strathclyde

Department of Curricular Studies

Please fill in the following details about yourself

Your University number: ....Your Lab Bench number:.......................

Gender: ☐ M ☐ F

This test is part of a study on the learning of jumping gene.
Please attempt ALL questions.
The outcomes from this test will NOT affect your course marks in any way.

(1) The table below shows eight elements related to transpositions.

Divide the elements into 2 groups of elements, four in one category, and four in another.

(Use the numbers of boxes to show the groups)

Cut & paste transposition 1	**Ds** (Transposable element) 2	Copy &paste transposition 3	Human beings 4
DNA Transposon 5	Retrotransposons 6	**LINE &SINE** (Transposable element) 7	Corn seed 8

Group A	**Group B**

(2) Which **one** of the following causes a corn seed to be *spotted* (speckled)?
(Tick one box)

☐ Stable gene mutation
☐ Unstable gene mutation
☐ Normal gene activity

Explain your choice in one sentence

....

(3) Which **one** of the following starches causes the **pea seed** to be *smooth* (round)?
(Tick one box)

☐ Amylopectin
☐ Amylose

Explain, in one sentence, why this happens.

....

....

(4) Here are six items.
Tick ***three*** that are directly related to each other.

☐ Gene ***c*** (mutant)
☐ Chromosome 9
☐ Purple corn seed
☐ Gene W (wild)
☐ Unstable mutation
☐ RNA

What can you explain with the help of these three related elements? (One sentence)

....

....

(5) Here are six items. Three of them are directly related to one another.
Tick *three* that are directly related to each other

☐ Gene *W* (wild)
☐ Gene *c* (mutant)
☐ RNA
☐ Active starch branching enzyme
☐ Transposable element
☐ Amylopectin

What can you explain with the help of these three related elements? (One sentence)

....

....

(6) Which **two** of the following do have the ability to increase the genome size?
(Tick two boxes)

☐ DNA transposon
☐ Retrotransposon
☐ Retrotransposition
☐ Conservative transposition

Explain, in one sentence, why this happens.

....

....

(7) Suppose you are presented with two genes responsible for **corn seed** pigmentation.
One is switched on, producing purple pigment, but the other one is switched off, not producing purple pigment.

What will be your conclusion about the size of both genes (one sentence)?

....

....

(8) Suppose there are two genes of **wild type** responsible for the **pea seed** shape.
If one of them is invaded by a transposable element, what *structural* and *chemical* changes will you observe in that gene?

....

....

(9) Suppose you are given two genes responsible for **corn seed** pigmentation.
One of the genes carries "Ds" (transposable element) in it and showing a stable mutation, while the other gene is without Ds.
The presence or absence of element Ds is a source of information.
What would you deduce about the **phenotype** of the corn seed, its **genotype, and gene size?**

Fill in the details of your answer in the following table.

Gene	Phenotype	Genotype	Gene size
Gene 1 (carrying Ds)			
Gene 2			

(10) You are presented with two genes (gene 1 & gene 2) of different size: gene 1 is bigger.

However, both are responsible for the pea seed shape.
What would you deduce about the **phenotype, the genotype and the type of starch** the seeds contain just by looking at the gene size?
Write your answers in the spaces provided.

Genes	**Phenotype**	**Genotype**	**Type of starch**
Gene 1			
Gene 2			

(11) Fill in the details about **corn seed** in the empty spaces row by row.

Enzyme Transposase (Present/ absent)	**Seed colour in corn**	**Genes & transposable element (TE)**	**Mutation/ normal gene activity**
1:present			Stable mutation
2:		Gene *C* (wild type)	
3:			Unstable mutation
4: absent			
5:	Spotted (speckled) corn seed		

(12) Look at the 12 boxes below.
The elements in the following table form a sequence of thought showing the production of ***speckled corn seed.***
Using the numbers, select the boxes you need and place them in the correct order.
The first box in the sequence is box 5 while the last box is 12. You may use as many boxes as you wish to make the sequence.

Ds jumps out of gene "*c*" 1	Switched on gene produces purple pigment 2	**Ds again switches off the gene "*C*" to gene "*c*"** 3	**Stable mutation causes a yellow corn seed** 4
Insertion of Ds into wild type gene "*C*" 5	Wild type gene "*C*" is switched off to be a mutant gene "*c*" 6	Ds jumps into switched on gene "*C*" for the second time 7	**Switching on and off of the gene causes unstable mutation** 8
Gene "*c*" is switched on to gene "*C*" 9	Stable mutation does not produce purple pigment 10	Switched off gene "*c*" doesn't produce purple pigment. 11	Thus speckled or spotted corn seed results in. 12

Write the numbers of relevant boxes:...

Write the correct sequence: 5,.. ....,12

(13) Look at the 12 boxes below.
Some of them form a sequence of thought showing the production of round and wrinkled pea seed.

Gene "*w*" Mutant gene 1	Gene "*W*" Wild type gene 2	Codes for inactive starch branching enzyme 3	Insertion of transposable element into wild type gene 4
Codes for active starch branching enzyme 5	Amylose is synthesised 6	Two different phenotypes 7	It retains water 8
Round seed 9	Amylopectin is synthesised 10	Not efficient in water retention 11	Wrinkled pea seed 12

Select the number of box (es) which contain the elements relevant for the:

(i) Round pea seed: ....

Arrange the selected elements, for the round pea seed, in sequential order (use the given number in the boxes).

(ii) Sequential order: ....

Select the number of box (es) which contain the elements relevant for the:

(iii) Wrinkled pea seed: ....

Arrange the selected elements, for wrinkled pea seed, in sequential order (use the given number in the boxes).

(iv) Sequential order: ....

(14) Draw a ***diagram*** (or series of diagrams) to ***illustrate the phenomena of transposition causing wrinkled pea seed. (You should aim for clarity in explaining exactly what happens)***

Performance Test for Case Study in Pakistan

Please fill in the following details about yourself

Your Name: ....

Your Roll Number: ....

Name of the college ....

Please attempt ALL questions

(1) The table below shows eight elements related to transpositions.
Divide the elements into 2 groups of elements, four in one category, and four in another.
(Use the numbers of boxes to show the groups)

Column A	Column B
1: Replicative transposition 2: Normal genome size 3: Human beings 4: DS (Transposable element) 5: LINE & SINE (Transposable element) 6: Corn seed 7: Bigger genome size 8: Conservative Transposition	**Group A**
	Group B

(2) What can you explain with the help of following information?

(a) *Bacteria causing food poisoning are present in the intestinal tract of a patient admitted into a hospital. These bacteria contain insertion sequences in their genome. A bottle of medicine (antibiotic) is lying beside the bed of the patient which is Tetracycline.*

(b) A patient suffering from lung infection caused by bacteria carrying transposon lying on his bed in a ward. A bottle of medicine, tetracycline (antibiotic), is lying beside his bed. It is the only available medicine to him and it is not proving to be effective as well).

(3) Explain the <u>cause and effect</u> of the following elements

(a) Presence of anthocyanin

(b) Unstable gene mutation

(4) Here are six items.
Tick *three* that are directly related to each other.

☐ Gene *c* (mutant)
☐ Chromosome 9
☐ Purple corn seed
☐ Gene W (wild)
☐ Unstable mutation
☐ RNA

<u>What can you explain with the help of these three related elements? (One sentence)</u>

(5) What happens to a gene (responsible for pigment production) in corn seed, when a transposable element jumps into it and stays there permanently?

(6) Suppose you are given two genes responsible for corn seed pigmentation.
One of the genes carries "Ds" (transposable element) in it and showing a stable mutation, while the other gene is without Ds.
The presence or absence of element Ds is a source of information.

What would you deduce about the phenotype of the corn seed, its genotype, and gene size?

Fill in the details of your answer in the following table.

Gene	**Phenotype**	**Genotype**	**Gene size**
Gene 1 (carrying Ds)			
Gene 2			

(7) You are given purple and yellow *corn seeds.*

What can you deduce about the genotype, gene size and the presence or absence of transposable element in

case of these corn seed?
Write your answers in the space provided.

Corn seed	**Genotype**	**Gene size**	**Transposable element Yes/No**
Purple seed			
Yellow seed			

(8) Explain in detail why and how a corn seed becomes speckled?

(9) Draw a diagram or series of diagram to illustrate why does a corn seed become speckled?

Intervention Effectiveness Survey

What Do You Think?

Your Registration Number: ………………

Your Lab Bench Number ………………

You have completed several exercises in laboratory times, all relating to themes connected to the idea of jumping gene.

Tick one box on each line to show how you found this experience of completing the exercises on transposition.

		Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
1	I understand the subtopic "jumping genes" better now.					
2	The group work was NOT useful to develop understanding.					
3	The activities helped me to visualise levels in a system.					
4	I was never taught in the past to think in terms of levels.					
5	I can now see living systems are arranged in levels.					
6	I can now see the link between the molecular level and organism level.					
7	The activities did NOT add to my understanding of transposition.					
8	The idea of levels in genetics was evident to me for the first time when I completed these exercises.					
9	I can easily relate the phenomena at molecular level to the organism level in the case of the wrinkled pea seed.					
10	I can apply this sort of thinking with the other topics in genetics.					
11	The activities in the worksheets helped me to understand the links between different levels of biological organisation.					
12	I do NOT understand the phenomena of transposition in the corn seed any better than before.					
13	I liked the presentation of the material about transposition, pea seed and corn seed in a different way from my textbook.					
14	I still need to have additional support to understand transposition and the speckled corn seed.					
15	The questions in the worksheets were helpful to make me think.					
16	I would appreciate to have such level based activities for other difficult subtopics in genetics.					
17	My teacher explained the phenomenon of transposition and corn seed in his lecture with the reference to different levels.					
18	I have developed a way of thinking in levels after these activities in laboratory times.					
19	As a result of these activities, I have started thinking in terms of levels while studying biology.					
20	I realise that thinking in levels can make genetics easy to understand.					

Learning About Genetics

Your Thoughts

Your University Number: ....

(1) Many students have said they find genetics is difficult to learn.
Here are some reasons.
Select the reasons which are ***true for you.***
Tick as many as you wish.

☐ I find genetics difficult to understand.
☐ There is too much information involved in genetics.
☐ The large number of genetic terms make it difficult.
☐ There are too many concepts to grasp.
☐ It involves chemistry and this makes it difficult.
☐ Genetics is not related to observable phenomena.
☐ I do not have enough time because of workload of other subjects.
☐ The way I was taught at school did not suit me.
☐ Genetics deals with the most complex part of living beings.
☐ Some concepts involve mathematics and this makes it difficult.
☐ I find it difficult to visualise things at the microscopic level.
☐ To understand genetics requires me to hold too much information at one time.

(2) Think of how you were **taught biology at school.**
[If you did not study biology before coming to the University of Strathclyde, ignore this question]

Here is a list of some ways you might have experienced.
*Place them in order, showing which was **used most**.*

(A) My teachers taught by giving information as in a lecture;
(B) My teachers allowed us to work in groups and to discuss;
(C) My teachers used much visual material (like diagrams, computers, graphics and models);
(D) My teachers tended to rely on the use of text books;
(E) My teachers encouraged me to work mostly on my own;
(F) My teachers held discussions with us as a class;
(G) My teachers used past examination papers to guide the work.

Used most ☐ ☐ ☐ ☐ ☐ ☐ ☐ *Used least*

(3) Think about the way you **like to learn to prepare for an exam.**
*Pick the **FOUR** aspects which are most true for yourself and put them **in order of importance.***

(A)	I like working with others	(B)	I like practical activities
(C)	I like doing things for myself	(D)	I prefer the lecturer to provide everything
(E)	I rely on memorisation	(F)	I rely on understanding
(G)	I enjoy intellectual challenge	(H)	I avoid difficult material
(I)	I like practical implications to be emphasised	(J)	Theoretical material is important to me

Most Important: ☐ ☐ ☐ ☐

Think of the drawings you were asked to do on some of the activity sheets.
(Tick as many boxes as you think apply to you)

I found it difficult to draw diagrams because

☐ It was hard to visualise microscopic information.
☐ It was hard to link different levels.
☐ It was hard to pull all the components and levels together.
☐ I found it difficult to think in terms of levels.
☐ It was hard to think of a way to put all the components and levels together in drawing.
☐ I realize that there was too much information to recall at the same time for drawing. (like recalling components, levels, and then links between them)

Any other reason?

....

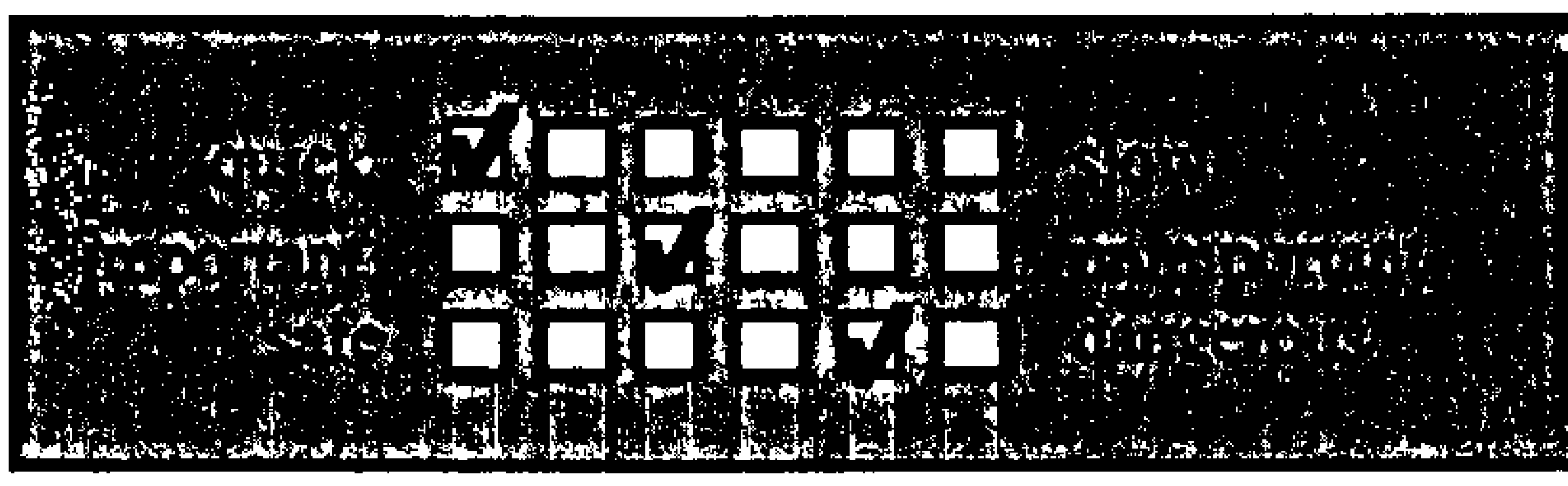
....

Thank You for Your Help

(4) Think about the way you prefer in **studying genetics**
Tick the THREE which most apply to you.

☐ Reading lecture notes ☐ Reading the text book ☐ Making revision notes
☐ Talking to others ☐ Using website ☐ Trying previous exam papers
☐ Using quizzes on Spider

(5) Here is a way to describe a racing car:



The positions of the ticks between the word pairs show that you consider it as <u>very</u> quick, slightly more important than unimportant and <u>quite</u> dangerous.

Use the same method of ticking to show your views below.
Think abut genetics, biology and the way science works.

I enjoy studying genetics							Studying genetics is boring
Genetics is difficult to understand							Genetics is easy to understand
Genetics knowledge is only facts							Genetics knowledge involves concepts
Genetics knowledge is microscopic							Genetics knowledge is not only microscopic
Genetics knowledge is abstract							Genetics knowledge is concrete
Genetics knowledge is isolated information							Genetics involves linking information
Scientists tend to disagree with one another							Scientists tend to agree with one another
Genetics knowledge is static							Genetics knowledge is dynamic
Genetics knowledge is relevant to our daily life							Genetics knowledge is irrelevant for daily life
It is important to make the public aware of new research findings in genetics							It is not important to make public aware of new research findings in genetics
Genetics knowledge in our text books is absolutely true							Genetics knowledge in our textbooks is not absolutely true
Scientific research finding are influenced by the scientists' biases							Scientific research finding are not influenced by the scientists' biases
The objects of study, living things, in genetics appear to be complex systems.							The objects of study, living things, in genetics are not complex systems
I can see different branches of biology connected.							I cannot see different branches of biology connected.

(6) How often do you use the university prescribed website for studying genetics.
Tick ONE box.

☐ Every day ☐ Once a week ☐ Never ☐ Near the exam

(7) Here are some reasons for avoiding the use of website for studying genetics

*Tick the **FOUR** which most apply to you.*

☐ There are too many links
☐ It is too time consuming
☐ I rely on my teacher
☐ There is too much information on the screen
☐ It is difficult to extract relevant information
☐ I find it hard to follow the connections
☐ I do not have convenient access to the internet
☐ I prefer reading the text book
☐ It is not well structured
☐ When I move, I forget the previous screen

Thank you for your help
We hope this will help future learning in genetics

Anchor Exercise

Your name ………………….

Your Roll number ………………….

Gender (Male/ female) ………………….

There is no right and wrong answer for the following question.

Arrange each of the following lists in any appropriate order you like.
(*Use the letters to express your answers)*

(A) A piece of liver
(B) Cell
(C) Bull
(D) Liver
(E) Chromosome
(F) Gene
(G) A herd of cattle
(H) DNA segment carrying few genes

Logical order: ……………………………………………………………………………

(A) A man
(B) Human beings
(C) Male hormones
(D) Y chromosome
(E) Nucleus
(F) Cells
(G) Heart
(H) Biosphere

Logical order: …………………………………………………………………

(B) Tissue
(B) Molecules
(C) Cell
(D) Organism
(E) Organ
(F) Chromosome
(g) Gene
(H) DNA segment
(I) Population

Logical order: ……………………………………………………………………………

(A) Single gene
(B) Bacterium
(C) Chromosome
(E) Ecosystem
(F) Biosphere
(G) Population
(H) Communities

Logical order: ……………………………………………………………………………

(A) Universe
(B) Planet earth
(C) NWFP
(D) Abbottabad
(E) Asia
(F) Continents
(G) Pakistan
(H) Solar system
(I) Degree college No 1, Atd.

Logical order: ……………………………………………………………………………

(A) Your mother's jewellery box
(B) A piece of her broken gold ring
(C) Shiny gold dust form piece of broken ring
(D) her broken gold ring
(E) Her gold jewellery
(F) A gold particle from the gold dust
(G) An atom of gold
(H) Nucleus of the gold atom
(I) Her collection of jewellery

Logical order: ……………………………………………………………………………

Support Exercise

Read the following text and present it in diagrammatic form.

An African tribe is living in a forest. They want to kill all the elephant living in that forest for getting their beautiful tusks. They are also cutting the trees to use the wood for fuel. They also hunt small animals like rabbits and birds. They go for fishing as well in a big lake far from the forest. The lake is a rich source of different types of fish. They have fields of corn plants and they eat the corn seed. They eat small red berries as well. They also grow spinach and eat the leaves of spinach. The leaves of the spinach are very green because of the large number of chloroplasts which take part in the photosynthesis. There are millions of bacteria present on the surface of the spinach leaves.

The wife of the tribal chief has all sorts of health problems. Two days ago the wife of the tribal chief ate the spinach leaves in her dinner and she has got stomach problem. She is also suffering from a heart disease and she has been told that it is a gene related hereditary disease which she has inherited from her mother. She is also having problems with her lungs which is suspected to be TB caused by bacteria. Because of all these health problems she is very unwell and stays in her bed almost all the time.

What Do You Think?

Your Registration Number: ....
Your Lab Bench Number ....

You have completed several exercises all relating to themes connected to the idea of transposition.

*Tick **one box on each line** to show how you found this experience of completing the exercises on transposition.*

		Strongly agree	***Agree***	***Neutral***	***Disagree***	***Strongly disagree***
1	I found the oral questions helpful for understanding the topic					
2	The questions in the worksheet helped me to visualise levels in a system.					
3	The questions in the work sheet were helpful to make me think.					
4	I have not answered questions like this before					
5	The questions in the worksheets helped me to understand the links between different levels of biological organisation					
6	The idea of levels in genetics was evident to me for the first time when I completed these exercises.					
7	I can apply this sort of thinking with the other topics in genetics.					
8	I would appreciate to have such level based activities for other difficult subtopics in genetics.					
9	I have developed a way of thinking in levels after these classes					
10	I realise that thinking in levels can make genetics easy to understand.					
11	I found the model useful for visualising the organisation of the living world					
12	The model helped me to organise my thoughts					
13	The model me to arrange the knowledge in my memory					
14	The model helped me to think / in terms of levels					

Questions for group discussion (Group report)

(1) The questions in the worksheet were perhaps unfamiliar.
You may have found them difficult to answer. Discuss this.
Give at least three reasons why they were difficult to answer.

(2) What did you like about the questions in the sheet?
Explain why they helped your understanding.

(3) What did you ***not*** like about the questions in the worksheet?

(4) What did you like about the models?
In what ways did you find the model useful?

(5) What did you ***not*** like about the models?
In what ways did you find the model unhelpful?

(6) What is your opinion about the reading material?
In what ways the reading material was helpful?

(7) List things you liked or disliked you like about the presentation of the text in the booklet?

Digit Span Test

This is carried out in the following way:

(1) Give each student a sheet with spaces for writing down answers
Instruct them to write their names, matriculation numbers or some other identifier.

(2) Read them the following instructions:

"This is an unusual test. It will not count for your marks or grades in any way. We are trying to find ouit more about the way you can study and this test will give sus useful information. You will not be identified in any way from it.

I am going to say some number. you must not write as I speak. When I stop speaking, you will be asked to write the numbers down the boxes on your sheet.

Are we ready? Let's begin.

(3) You say the numbers exactly at a rate of one per second (use a stop watch or heart beat to keep your time right. You allow the same number of seconds fro the students to write down the answers. Thus, if you gave the numbers: 5,3,8,6,2. You give them five seconds for writing them down. I follow the procedure:

"5,3,8,6,2 - 'write' - five seconds allowed for writing, then 'next'"

(4) Here are the numbers used by Elbanna in his early work:

5 8 2
6 9 4

6 4 3 9
7 2 8 6

4 2 7 3 1
7 5 8 3 6

6 1 9 4 7 3
3 9 2 4 8 7

5 9 1 7 4 2 8
4 1 7 9 3 8 6

5 9 1 9 2 6 4 7
3 8 2 9 5 1 7 4

2 7 5 8 6 2 5 8 4
7 1 3 9 4 2 5 6 8

(5) You now give a second set of instructions.
"Now I am going to give you another set of numbers. However, there is an added complication!
When I have finished saying the nunmbers, I want yo to write them down in reverse order.
For example, if I say "7,1,9", you write it down as "9,1,7".
Now, no cheating!! You must not write the numbers down backwards.
You listen carefully, turn the numbers round in your head and thenm write them down normally.
Have you got this? Let's begin."

(6) Here are the numbers:

2 4
5 8

6 2 9
4 1 5

3 2 7 9
4 9 6 8

1 5 2 8 6
6 1 8 4 3

5 3 9 4 1 8
7 2 4 8 5 6

8 1 2 9 3 6 5
4 7 3 9 1 2 8

9 4 3 7 6 2 5 8
7 2 8 1 9 6 5 3

(7) This is the version used for adults (those over 16). With younger children, it will need adjusted by removing the larger sets of numbers.

(8) Marking: the main thing is to be consistent. Ideally, if a person achieves at, say, 4,5,6 and 7 but fails at eight digits, then their working memory is 7. However, they can often fail an odd one (by simple slips) or suceed at one at, say, eight digits and fail at the other. I use the simple rule that, for a single failure followed by two correct answers, I ignore the failure. For those who fail at one and succes at the other at one leve, just be consistent: I would give them that level.

Note also: check the number sequences above to check if any sequence of nuimbers has any pattern in your cultural setting (like a radio wavelength, a car registration code or whatever...)

(9) The student answer sheet will look something like:

Student Answer Sheet

Your name: (or other identifier): ....

Write the numbers in the boxes below

Digit Backwards Test

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Appendix E

Interview Quotations

(Pakistan and the Netherlands)

Quotes related to Systems Theories and Biology Education:

These theories present multiple phenomena of scientific research (2) The knowledge of these theories can be useful for the biology students who are intending to try to understand complexity and coherence in biological systems (2) it would be worthwhile to introduce the major concepts rather than the formalised theories in the teacher education (2). general systems provide a general frame for the whole biology. it provides structure... the field of biology id fragmented... if you take seriously the relationship between levels of biological organisation... it says that you should not separate biological themes about biological levels (2).

...the general systems theory throw light on the structure and nature of the systems, cybernetics talks about how does the system regulates and systems dynamics talks about the evolutionary aspects of the open systems(4). Teachers have to be aware that they use implicitly a lots of concepts from different levels of biological organisation and students do not know always ... make it explicit that you use different concepts from different levels... you can design your educational material in that way that you can distinguish which level of organisation the content is related to.'(4)

... These theories are the reflection on the biology knowledge and they indicate what does it mean to have biological thinking or thinking in biological way. It is helpful and important for training students who want to become professional in educational communication to have the knowledge of systems theories. It is vital for the teachers to know them because it is important to reflect on the nature of the discipline one wants to teach... it should be considered as an important part in biology teacher training (3). The fundamental concepts about the discipline and ... must be known to the students, whether they are studying biology or getting ready to teach biology (3)

general systems theory...is about biological levels...yo yp strategy, going up and down between the levels of biological organisation, that is the way to look at coherence, look at what r the things really interrelate, how concepts at different levels of biological organisation relate to each other...9 ...dynamic systems theory... modelling is important...static models are basic...showing how things interrelate...at certain point you can no longer out all details in your model(3)

General systems theory... to give students some idea of how different levels are nested, cybernetics can explain simple interactions and simple systems and systems dynamic could be helpful in more sophisticated ecosystem research...complexity theory...proverbial butterfly effect idea is becoming stronger in eco system management (6)

My teaching style has changed by the introduction of these theories... I use them in workshops with teachers... to give them idea to make use of them in teaching" (1)

Quotes Related to Systems thinking' Impact:

I think it will equip you for living as well cautious citizens in a complex dynamic society, it makes you responsible (3).

We shall make less stupid choices (2)

It will help them to be good decision makers and managers. It will help students to behave and act sensibly with a systems perspective (1)

Quoted Related to Need of Systems thinking

... the idea that we can make complex things simpler by using systems model... complexity has triggered people... nowadays we look at natural science .. as first resort because it is the dominant concept of nature and thus applying natural science concept to reduce complexity that is I would say the basic intuition or hope that drives people to grasp this concept (2).

..., there is too much biology and u can not know all the facts there is a overload; and second the lack of coherence and it relates to that first problem and then I think if we want to learn for understanding we need to give some more general tools; learning for understanding, not only learning facts, and learning for reproduction, learning for understanding makes that you think about what is unifying our discipline (3).

... depends on some people getting interested in ST and getting involved in biology education and ...I started with System thinking... not , Bertalnnfy, with the communication ...is based on systems thinking and my interest started what happened in interaction between people that is why my interest started and the communication theory provides u frame work for analysing the personal communication ... , communication theory was helpful in analysing interaction in class room ... I realised that it might be interesting to use the same line of thinking not only for analysis of interaction but also for the content of biology... systems thinking might be useful both for the interaction side of biology education and also for biology content and that idea that St could be used for selecting, structuring biology content (2).

You need to have a some kind of coherence between different concepts. It is more or less trying to find brining coherence in all the fragment concepts and I think systems thinking is an important tool in reaching that (4).

... like for genetics... students find it difficult to learn... you see that the problem is that biology is so big in terminology and processes and all of them are connected to one another and when you help them to see in a systems way, they can understand it better...(5).

Quotes Related to Brining Systems-thinking in Education:

My recommendation, from the fact that it is hard to define systems thinking as an abstract thing, I would always say take into a context and then show what you can do with (6).

Everything is in content. Formal lectures will be boring ... I use metaphors or otherwise I use real biology content but I never teach about systems thinking and may be what I do is, I do some teaching but at the end in the reflection phase, I tell them something. you could say this organism is a system what could be the borders. Could u name some imp factor, or not so imp factors, which could pass the border, that sort of things but always in content (1).

I think it is the constructivist, I think it is helpful, I told u before that ST that u learn from experience so there is intuition or intuitive notion and u can build on it and reflect on it and verbalise it and extend it conceptually... St helps you to tell the biological story or the story of sociology of society, so it is a way of ordering the different facts and concepts and putting them into perspective, putting things into perspective. .. Both are important, if it is not formal lecture it should be narrative and inspiring lecture, telling the systems story (3)

Formal lecture is hardly ever helpful.... I think biology is very appropriate subject for introducing Systems thinking and for the sake of student you would start with biology and from biology you will develop systems thinking or, some levels or some kind of systems thinking ... the idea of systems students can use it in different context and the other way of thinking is also opened which means that u can talk about systems and ask them to apply for example the relationship between different LOB in a new topic allowing opportunity to apply what they learnt from systems thinking.(2)

systems thinking should be grounded in biology content ...develop some kind of biological context where systems view or approach may still be implicit and afterwards based on biological knowledge you can develop may be in an explicit view on systems thinking u can make systems thinking explicit... I think, eventually systems thinking should arise from biological content and u should of course arrange biology education how to reach and make systems thinking explicit. (4)

I think biology based on systems thinking is better...but at some stage you have to do both' (5).

Quotes Related to Systems-based Reading material

basically you want to show how the material flows... show them link and connections and also the cyclic nature of the flow of the chemicals... chain of interrelated events (6).

I always liked to start at the concrete...with pea, guinea pigs and now I always start with a problem for example my brother have sickle cell anaemia... the individual problem then we can go down to the gene... always go up and down. It is very important ... I would like the idea of levels of organisation, discrimination between important and non important factors... you have to make choices (1).

You should start bottom up and top down approach at the same time...tell them the story...levels of biological organisation, I think it is important to make it explicit...do not look at the isolated entities but bring the concept of network...if you do not know the gene and you know the phenotype, or u first of all if u know the gene you may know something about what is the phenotype, and if u know the phenotype on cellular level , you can predict perhaps what the disease u would have on the orgnisimc level.

It depends what aspect of systems thinking u have in mind. I think it is wise to take an example or theme which make sense in elaborating different LOB ... If you want to explore the relations between different LOB think it should be suitable to select a theme which involves processes at different levels of organisation... start at the concrete level ...when you start introducing systems thinking and that I would suggest anyway that you take examples or themes which contain several levels of biological organisation.'(6).

I think the content should be distinguished according to levels of organisation for example and also of the concept of different level should be related to one another somehow but what I also think, thinking back and forth between real life phenomena and systems model is very important (4).

... start at the organism level because that is the level students know and recognise it and they have their real life experience at that level and from there you descend a level and get familiar with the concept on the cellular level and try to connect... but in systems thinking you also have the horizontal level so when you are on the organism level then you have to think about the other humans to make horizontal connections (5).

Quotes related to Systems-based Teaching and Learning Activities

... there is a kind of educational environment like computers and this enables them to play interactively with models so to change the variables to see the consequences and then to compare that with some elements, some parameters of the actual system and they can get idea how these abstract models are related to concrete systems in reality... you have to have a reference in the real world so that you link up the concept in the model with the real world concept... for validation (6).

... modelling is an activity that has to do a lot with systems thinking may be making some categorisation, bringing some relationship, it means sketching, thinking what is imp what is not, sketching a relationship so we can have a concept map and for me it is important to have the element of time which is imp for dynamics. I would like to bring third dimension of time, how this systems is looking like tomorrow and in a year...(1).

It is very important the type of questions that you ask and that u exemplify to the students, that is why I said that teachers should be a model of ST. It should not take much time in asking question how does this relate to another level of biological organisation, or can u predict now that is the yo yo thinking...(3).

I'm always interested in rather complicated tasks and questions. We strongly believe that activities are required as a condition for learning something... sometime paper and pencil tasks are too simple and many students in particular, university students, pre university, secondary students, they do not feel invited by such simple questions, reproduction question... learning activities may be more cognitive work or something to do with your hands and then by doing things students are learning something and that is necessary to reconstruct and reflect on the activity which was executed ... (2).

...eco system is always the static concept and again same with the concept of cell. Students understand concept cell as a static thing which is there, has component and there is happening something and that is not dynamic picture and that would be more close to the recent developments in biology that it is worthwhile for students to have a dynamic picture of eco systems, we know and we know from literature when you ask students if u change on something in eco systems what will be the consequences of the things you are doing and in almost any case students are not able to foresee, but might be happen after the second step so the difficulty of that eco systems and cell as well that relationship between cause and effect might be changed and there are not mono-causal single causes , many processes of phenomena has multiple causes and that exemplifies the dynamics nature of biological systems (2).

.. I am not convinced about simple paper pencil based question activity. I'm searching for more involvement of students... I'm interested in higher order ways of thinking and acting, and I think it is necessary also because ST is complex off course and this is not a , you do not learn ST if you are just recalling some definitions (2).

they should be actively involved in the process of modelling.... They should be engaged in thinking about structure but also relations these between structure and also about the functions of these structures....they should interrelate different parts of biology systems. Perhaps u can engage them in a kind of yo yo thinking. At each level of organisation u could describe some kind of phenomena and student should be able to describe this phenomena at each level and should be interrelate them, some kind of genetic mutation , describe it and link it to the disease at organism...I think u should really engage in thinking back an d forward, at cellular, and molecular level... think backward and forward between different kind of models, because well, u can see a mother in real life, you can see a picture of mother, and u can well see all kinds of deferent models at all levels of organisation, u have all kinds of cellular models which predict all kinds of cellular process (4).

... doing modelling is not my favourite because that is really a model and it is becoming really abstract and I think in this age the difficult part is that students learn a lot of difficult chapters in biology like blood circulation, respiration, energy and flow and they do not know understand that they are all connected with one another and I think that u should keep it at concrete level, that is personal but may be after that when they understand then they can develop model. I think , models, for in system, when u have solution, how two systems work together and then they have visual on computer screen then they see that visualisation helps (4).

Quotes related to Assessment and Systems Thinking:

Presenting complex content is a good way of making students find their way in this information belonging to different levels of biological organisation and the questions must not be requiring them to recall, they must involve in discussion, arguing and thus finding their way...systems thinking is not asking for factual knowledge.... You should not just ask, what is this or that, but why is this or that, why questions ...'ask them complex questions'; ask questions which ring the bell for seeing things connected; let them connect different elements of knowledge...let them think in retrospective sense, what happens if we change this, what the effect will be ...(3).

...what would happen if this goes out... should present a complex context... questions should be in the form of a context and context should be complex... put them in a situation where hey have to argue, discuss and find a way in a big bunch of information... ask them to take elements out of the content...show relations... give them text and ask them to convert it into diagrammatic presentation or mind map and then you see how complete it is (1).

...ask students to describe or explain a phenomenon... relate their explanation to the levels of biological organisation (4).

Quotes Related to Definition of Systems Thinking:

It is looking to the world, part of the world as a system, being composed of factors, building block and relation between those building blocks. One can take whole world as a systems, or individual or population(1).

it means that it is a way not looking at the isolated phenomena but also in the broader context putting them in broader context of the whole organism. It has always to do with the whole which is composed of minor wholes which interact and work together (2).

You recognise somewhere boundary and also and you consider things inside the boundary as belonging to the systems and outside the boundary as outside the system (3).

Being able to interrelate the parts of a systems and relating them to the function of the larger whole and larger whole could be a machine could be the world could be every thing (4).

ST is the hope that it is possible to grasp or embrace the complexity of the world or part of the world in a kind of a conceptual, model which is compatible with natural science (6).

Quotes about Reading Material

Method to convert the text into story was very good and impressive and we liked it and the text gives us minute detail and also it is written in easy to understand language, diagrams were very helpful, interesting and colourful. They caught our attention, when they appeal to your eyes then you want to read them (g2c1).

We enjoyed, it was interesting, diagrams were nice, colourful things made us excited (g1c2).

We could feel as a new friend comes into class then he presents himself in the class and then we understand, and then these new things familiarise us with their name and background, we were taking it as a movie in front of our eyes (g3c1).

We liked the presentation ... with Barbra Mcclintock, we imagine the seed in front of us, we can come to know about biological level and concept, we can understand links, connection between different things in the biology .it is different from our text book and this booklet helped us to understand biological phenomena in an interesting way... It helped in organising information in an organised way (g4c1).

Presentation in the form of letters and story was good and appreciated because we realised that something was happening in front of our eyes because it explained itself before us. This method was a light method in comfortable environment and we were not pressurised it was light work. So the links were in front of you, in our real text language is difficult so language was easy. We pressurise our self to keep the information in memory. But this method we found easy and light. Here we studied in the levels and then we can keep the information in our mind (g5c1).

Way of presentation was easy to understand, easy language, and was enjoyable. It was just like reading a story book where you can not stop reading and want to know what happened in the end. After reading these book lets, we feel that it would be nice to have such reading in other topics as well because it integrate the knowledge and information in your mind and develops concepts ... The reading was like watching a movie. Everything was new of the booklet as compared to our book. It was a story telling method, explanation was with the mentioning of levels and using the concept of level is the best way to teach biology (g2c2).

We could see in our imagination because we had this model in our mind and then we were reading and we could see (g3c2).

Zooming in and zooming out, levels were interesting, story telling method helped us a lot. Story helped us to retain the material in memory...We liked going up and down in thinking and reading (g4c2).

I'm a gene, genome, in this manner anything is telling us about itself. It is a best way (g1c1).

Comments about Systems Model in Biology

Such models were never in our minds and never though that biology could be presented in such a way which would helpful in such a broadening way (g4c2).

Different biological levels... were the main requirement for the students to understand the common and difficult content'(g1c1).

Models... were according to specific pattern and it also arranged our thinking in a specific pattern (g2c1).

Idea about the relation of the levels was new (g3c1).

Arrangement of level was very new for us (g1c2).

We have never used models and were never taught about the idea of levels (g4c1).

The method... was helpful to understand biological organisation, especially vertical and horizontal links, they were new to us, never heard of them (g3c2).

It was step wise, you go in different small steps from smaller in order to collect scattered information from all levels in order to understand

Models were incredible, we liked them very much, they were showing summary, they were showing boundary, open systems, components, levels,, interactions, everything was summarised and so model was easy and was giving us almost the full picture (g4c2).

Models were useful... we can understand, visualise, and recall and think according to this specific pattern (g2c1)

We liked the models because they helped us to understand the given content in the booklet and also to understand the vertical and horizontal relation and we come to know the levels of biological organisation from simple to complex and vice versa. We can visualise things given in the content in a systematic manner...We can understand the content which is given and can correlate with the model which help us in studying and imagining the thing which is given and we can correlate with the model and thus we can organise the things which are given in the model and then the content which is given in the booklet because it is easier to understand the content with the help of model (g3c1).

Models helped us in organising our thought and also enabled us to think in terms of levels and to understand the real concept of the topic, models make us familiar the new topic easily and by this method we can pick the new concept of genetics and organise the things by means of the model from a single thing to whole systems, by the model we can organise our diagrammatic concept in mind (g4c1).

Models were useful in organising our thinking in biological organisation level, we could easily understand the topic, because they present the whole picture of the text in our mind and we can easily understand what is given in the text, they are not time consuming... We can use it in answering our question in the exam ...they present the whole picture of the text in out mind and we can easily understand what is going on in the text (g5c1).

We can make models of the other difficult topics to understand in Diagrammatic form, we can see level, components and links between them(g1c2).

Models were best to explain the topic under study. It gave us a summary and we could see and understand everything, components, and processes. Model summarised the whole content and it helped us to develop picture of the text in our mind (g2c2).

It was helpful in answering the test questions and also in the diagrammatic representation in the work sheet... We can use it in other topics. We can understand what is happening at what level and we can use the representation as an example to be followed or the future...We got the basic idea and information, you had laid the foundation and we can build upon it. We can adopt it and use it for anything, any biological topic can be shaped like these units (g3c2).

With the help of this model we could see the whole picture and now we can use this model for studying and understanding the other topics as well (g4c2).

It has changed our thinking... we want to use this type of thinking with the other topics as well (g2c2).

Quotes about Work Sheet

(1) No experience with such questions:

We have never been taught in this way (g2c1). Never heard of such questions (g5c1). We did not have experience of such questions (g3c1).

(2) No mental readiness for such questions:

Our mind was not ready to attempt such questions…Most of the time in our class room tests or exam, normally our teachers give us questions like define gene or genome, but in sheet the questions were different...We write word to word definition and then we have to explain and describe… (g4c2).

We read the first unit in the same old fashion and then questions in the work sheet were not of the type we used to do, so the questions in first worksheet helped us to realise how we have to read, so the second unit we did reading keeping in view the type of questions (g4c2).

(3) No facts testing question:

The questions are normally straight forward and they say explain, or describe. But you asked about why and how so we had to think a lot (g5c2)

it was little bit difficult to understand questions in the beginning, they were different from routine, we normally do the question where you have to recall and reproduce but these questions demanded understanding. We could not answer just by reading them once; we had to understand the situation in the question before thinking about the answer (g3c2)

(4) No understanding of levels:

The questions were unfamiliar to us because we did not have understanding of levels…(g3c1)

We liked them, we were confused because of level but latter on we became familiar and used to with it and then...found them easy (g2c1).

Introduction of level made them interesting and easy (g5c1)

(5) Too much information in the question:

Questions were time consuming to understand...There was a lot of information.... We had to think a lot of things about the questions before we could answer (g2c1).

Short time... had to think a lot... look and summarise in our mind and then we had to pick up the answer. We had to wind up lots of things while understanding the question (g3c2).

The questions were difficult, We had to recall everything and We had to pick the related information and we found it difficult (g3c1).

We did not have enough time to think about the whole thing (g5c1).

We had to think about the whole picture before answering (g2c2).

(6) Required deep thinking:
We never thought so deeply about any information (g1c1).

We did not read deeply and questions were deep

The main thing which we appreciate about questions is that smaller steps which were given made us to think the large and complicated things (g1c1).

Appendix F

Chi-Square

Chi-square Test ($\chi 2$)

Chi-square test is said to be one of the most widely used tests for statistical data of a non-parametric nature. There are two different of applications of chi-square test. Only one is used in this study.

The statistic is used to compare a set of frequencies. It does not depend on any assumed distribution. In a 'goodness of fit' application of chi-square, a set of frequencies from an experiment is compared to the expected set of frequencies, based on a control group or on the random way things happen. This is not used here and is not discussed further.

Chi-square can be used as a contingency test. This is commonly used in analysing data where two groups or variables are compared. Each of the variable may have two or more categories which are independent from each other. The data for this comparison is generated from the frequencies in the categories. In this study, the chi-square as a contingency test was used, for example, to compare two or more independent samples like, year groups, gender, or ages. The data is generated from one population group. For example, it can be illustrated by a fictional example where the responses of males and females on a three point scale are compared:

	Positive	*Neutral*	*Negative*	
Male (experimental)	55	95	23	(All frequency data)
Female (experimental)	34	100	43	

This is converted to:

	Positive	*Neutral*	*Negative*	*N*
Male (experimental)	55 (44)	95 (96)	23 (33)	**173**
Female (experimental)	34 (45)	100 (97)	43 (33)	**177**
Totals	**89**	**195**	**66**	**350**

The expected frequencies are shown in brackets ( ), and are calculated as follows:

For example: 44 = (173/350) x 89

Chi-Square is calculated in the following way:

$$\begin{aligned}\chi 2 &= 2.75 + 0.01 + 3.03 + 2.69 + 0.09 + 3.03 \\ &= \mathbf{11.6}\end{aligned}$$

At two degrees of freedom, this is significant at 1%. ($\chi 2$ critical at 1% level = 9.21)
The degree of freedom (df) must be stated for any calculated chi-square value. The value of the degree of freedom for any analysis is obtained from the following calculation:

$$\mathbf{df = (r-1) \times (c-1)}$$

(where **r** is the number of rows and **c** is the number of columns in the contingency table)

Limitations on the Use of $\chi 2$

It is known that when values within a category are small (i.e. 5, as proposed by some writers (Wiersma, 1995)), there is a chance that the calculation of $\chi 2$ may occasionally produce inflated results which may lead to wrong interpretations. In this study, in order to avoid dubious conclusions, a 5% or 10 (whichever ism ore critical) category limit was imposed.

The Use of Chi-square as a 5 by 3 Contingency Test

A example (part 4 of the survey used after the new materials had been applied) illustrates the two approaches. Students responded on a 5-point Likert way (from strongly agree to strongly disagree) and frequencies are shown:

Group	SA	A	N	D	SD	Compare	$\chi 2$	df	p
1	6	15	13	13	4	*1 & 2*	3.7	3	ns
2	6	30	17	13	1	*2 & 3*	11.5	2	0.01
3	3	33	18	33	14	*1 & 3*	2.7	2	ns
						All	12.1	4	0.05

It is possible to compare each pair of groups in turn or it is possible to calculate the chi-square statistics using all 15 values. Both have been done here.

If the three groups have some kind of linearity about them (for example increasing age or length of experience), then using all 15 frequencies at once may be appropriate. In the case here, the three groups are three distinct sub-groups in a biology class. It is difficult to interpret the value form all 15 frequencies. Here it is better to look at the values obtained by comparing the groups in pairs as this shows where the significant differences actually lie.

Comparison Between Three Sub-Groups for Phase Two

Question	Gr'p	SA	A	N	D	SD	Compare	χ2	df	p
I understand the subtopic "jumping genes" better now.	*1*	12	49	15	2	0	*1,2*	3.7	2	ns
	2	16	39	28	1	1	*2,3*	3.2	2	ns
	3	9	50	23	8	2	*1,3*	3.7	2	ns
							All	6.9	4	ns
The group work was **NOT** useful to develop understanding.	*1*	3	15	27	27	6	*1,2*	0.7	2	ns
	2	3	13	29	34	8	*2,3*	0.8	2	ns
	3	4	14	36	34	4	*1,3*	0.5	2	ns
							All	3.5	6	ns
The activities helped me to visualise levels in a system.	*1*	3	34	27	9	3	*1,2*	2.0	2	ns
	2	4	49	21	10	1	*2,3*	3.9	2	ns
	3	5	41	36	9	1	*1,3*	0.8	2	ns
							All	4.8	6	ns
I was never taught in the past to think in terms of levels.	*1*	9	22	19	19	6	*1,2*	3.7	3	ns
	2	8	38	21	16	1	*2,3*	11.5	2	0.01
	3	3	30	16	30	13	*1,3*	2.7	2	ns
							All	12.1	4	0.05
I can now see living systems are arranged in levels	*1*	10	43	22	0	0	*1,2*	2.7	3	ns
	2	10	58	16	1	0	*2,3*	2.2	2	ns
	3	7	55	21	3	4	*1,3*	1.2	2	ns
							All	3.3	4	ns
I can now see the link between the molecular level and organism level.	*1*	6	42	25	3	0	*1,2*	3.2	3	ns
	2	8	56	16	5	0	*2,3*	5.2	2	ns
	3	5	47	29	8	1	*1,3*	0.4	2	ns
							All	5.3	4	ns
The activities did **NOT** add to my understanding of transposition.	*1*	5	13	27	24	9	*1,2*	3.8	1	ns
	2	4	4	26	46	5	*2,3*	1/7	2	ns
	3	3	17	25	42	4	*1,3*	1.8	3	ns
							All	2.2	2	ns
The idea of levels in genetics was evident to me for the first time when I completed these exercises.	*1*	2	19	28	21	6	*1,2*	0.5	2	ns
	2	4	15	31	31	3	*2,3*	2.1	2	ns
	3	1	24	24	29	12	*1,3*	0.5	2	ns
							All	6.2	6	ns
I can easily relate the phenomena at molecular level to the organism level in the case of the wrinkled pea seed.	*1*	8	28	36	6	0	*1,2*	1.0	2	ns
	2	5	38	31	11	0	*2,3*	0.8	3	ns
	3	6	34	36	14	1	*1,3*	0.3	2	ns
							All	1.6	4	ns
I can apply this sort of thinking with the other topics in genetics.	*1*	6	24	31	15	2	*1,2*	5.6	2	ns
	2	4	44	31	4	1	*2,3*	1.1	2	ns
	3	6	41	33	9	1	*1,3*	4.3	3	ns
							All	5.9	6	ns
Group 1 (Biology major)	N = 67									
Group 2 (Biology outside subject)	N = 68									
Group 3 (Pharmacy)	N = 101									

Question	Gr'p	SA	A	N	D	SD	Compare	χ2	df	p
The activities in the worksheets helped me to understand the links between different levels of biological organisation.	*1*	5	36	27	8	3	*1,2*	2.3	4	ns
	2	5	49	24	4	4	*2,3*	0.7	2	ns
	3	3	49	27	9	2	*1,3*	0.4	2	ns
							All	2.7	6	ns
I do **NOT** understand the phenomena of transposition in the corn seed any better than before.	*1*	3	8	25	37	5	*1,2*	1.9	4	51
	2	4	8	20	51	4	*2,3*	2.5	4	ns
	3	2	11	28	44	5	*1,3*	0.7	3	ns
							All	3.4	8	ns
I liked the presentation of the material about transposition, pea seed and corn seed in a different way from my textbook.	*1*	9	28	21	9	10	*1,2*	1.4	3	ns
	2	8	35	28	11	4	*2,3*	3.6	4	ns
	3	8	34	22	20	7	*1,3*	0,4	2	ns
							All	4.0	6	ns
I still need to have additional support to understand transposition and the speckled corn seed.	*1*	9	18	31	18	0	*1,2*	0.2	2	ns
	2	3	25	39	19	0	*2,3*	7.5	2	0.05
	3	6	41	25	15	3	*1,3*	4.3	2	ns
							All		4	ns
The questions in the worksheets were helpful to make me think.	*1*	8	36	21	9	5	*1,2*	0.5	3	ns
	2	6	43	20	15	1	*2,3*	2.6	4	ns
	3	4	40	29	15	3	*1,3*	0.5	2	ns
							All	2.0	4	ns
I would appreciate to have such level based activities for other difficult subtopics in genetics.	*1*	6	36	19	9	6	*1,2*	1.1	3	ns
	2	6	41	26	10	1	*2,3*	2.1	3	ns
	3	6	38	27	15	5	*1,3*	0.6	3	ns
							All	2.5	6	ns
My teacher explained the phenomenon of transposition and corn seed in his lecture with the reference to different levels.	*1*	2	21	37	18	0	*1,2*	1.1	4	ns
	2	1	21	38	23	1	*2,3*	0.5	4	ns
	3	1	24	42	21	2	*1,3*	0.3	3	ns
							All	1.6	8	ns
I have developed a way of thinking in levels after these activities in laboratory times.	*1*	3	19	43	10	2	*1,2*	0.8	4	ns
	2	4	24	41	15	1	*2,3*	0.4	3	ns
	3	1	27	47	14	2	*1,3*	0.2	3	ns
							All	3.1	8	ns
As a result of these activities, I have started thinking in terms of levels while studying biology.	*1*	2	21	40	13	2	*1,2*	2.4	2	ns
	2	4	25	33	20	4	*2,3*	1.1	3	ns
	3	2	24	41	18	4	*1,3*	0.6	3	ns
							All	3.5	8	ns
I realise that thinking in levels can make genetics easy to understand.	*1*	13	31	28	3	2	*1,2*	1.2	3	ns
	2	4	51	24	5	1	*2,3*	1.8	3	ns
	3	7	42	33	6	2	*1,3*	0.6	3	ns
							All	2.4	6	ns
Group 1 (Biology major)	N = 67									
Group 2 (Biology outside subject)	N = 68									
Group 3 (Pharmacy)	N = 101									

Correlation

It frequently happens that two measurements relate to each other: a high value in one is associated with a high value in the other. The extent to which any two measurements are related in this way is shown by calculating the correlation coefficient. There are three ways of calculating a correlation coefficient, depending on the type of measurement:

(a) With integer data (like examination marks), Pearson correlation is used. This assumes an approximately normal distribution.
(b) With ordered data (like examination grades), Spearman correlation is used. This does not assume a normal distribution.
(c) With ordered data where there are only a small number of categories, Kendall's Tau-b correlation used. This does not assume a normal distribution.

Sometimes, the two variables to be related use different types of measurement. In this case, none of the methods is perfect and it is better to use more than one and compare outcomes. It is possible to use a Pearson correlation when one variable is integer and other is dichotomous. The coefficient is now called a point biserial coefficient.

In this study, Pearson correlation and Kendall's Tau-b were used.