THE CONCEPTS OF GROWTH AND THE CELL: 
STUDENTS' ALTERNATIVE CONCEPTIONS AND THE NATURE 
OF CONCEPTUAL CHANGE 

by 

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF 
THE REQUIREMENTS FOR THE DEGREE OF 
DOCTOR OF EDUCATION 

in 

THE FACULTY OF GRADUATE STUDIES 
(Department of Mathematics and Science Education) 

We accept this thesis as conforming 
to the required standard 

THE UNIVERSITY OF BRITISH COLUMBIA 
July, 1990 

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Date August 24, 1990
ABSTRACT

Learning difficulties resulting from students holding conceptions of scientific concepts which are at variance with those presented in curricular materials have been identified in the literature in a number of areas of science. In this study a number of student learning difficulties related to the concepts of growth and the cell were identified. More specifically, this study was designed to investigate whether alternative conceptions held by students prior to instruction were, in part, responsible for these learning difficulties. The study also investigated whether omissions in instruction contributed to these learning difficulties. Finally, the study examined changes in student conceptions after formal instruction.

Through concept analyses of growth and the cell, two semi-structured interview protocols were developed. The Growth Protocol was used to interview students in Grades 3, 5, and 7 and the Cell Protocol was used to interview students in Grade 10. The students in Grades 3 and 10 were interviewed both before and after instruction. The conceptions of the students identified in the transcripts were classified into a number of categories specific to the constituent concepts of growth and the cell.

Students at all grade levels were found to hold a wide variety of alternative conceptions regarding the concepts in
question. The majority of these alternative conceptions were identified in more than one student and did not reflect current scientific or curricular understandings of growth or the cell. Rather, it seemed that these alternative conceptions reflected student attempts to make sense of concrete experiences with phenomena in their surroundings. After instruction at both the elementary and secondary level, the majority of students did not incorporate most of the scientific concepts as they were presented during instruction.

The older students did not hold a conception of cell differentiation nor did the majority of students link the microscopic phenomena of cell division with the macroscopic phenomena of growth in organisms other than humans. The variability of alternative conceptions of mitosis and meiosis after instruction strongly suggested that the students experienced learning difficulties with respect to these concepts.

The results of this study imply that in order to effectively move the learner from alternative conceptions to scientific conceptions both curricular and instructional strategies must shift their emphasis from one of presenting only disciplinary knowledge to one of considering also the prior knowledge that the learner brings to the instructional setting.
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ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Dr. G.L. Erickson, Dr. J.R. Coombs, and Dr. M.F. Hoebel for being members of my thesis committee and for discussing the manuscript with me.

I am especially indebted to my thesis advisor Dr. Gaalen Erickson for providing me with the opportunity to do this research and for his continued help and assistance which he has offered throughout the duration of this study.

Also, I would like to thank Mr. John Kavelec, Dr. Robin Liley, and Mr. Reg Wild for the example, help, and guidance they have given me during my studies.

I am very grateful to my wife Mary and my mother and father for the unending patience and support which they have provided over the period of this research. I am also grateful to Phyllis and James Trayner for their inspiration.

This work was supported by Social Sciences and Humanities Research Council of Canada Doctoral Fellowships and University of British Columbia Graduate Doctoral Fellowships to the author.
CHAPTER ONE

INTRODUCTION

1.0 Background to the Problem

One of the most important ideas in modern biology is the cell theory. In its simplest form, this theory postulates that the cell is the basic structural unit of all living things and that all cells arise from other cells. These two propositions provide not only a working definition of life but also serve to unify the knowledge of cytology, biochemistry, genetics, pathology, and virtually all other areas of research in biology and medicine. Furthermore, the theory serves as a conceptual bridge between microscopic and molecular phenomena such as runaway cell division, nondisjunction, and lymphocyte-virus interactions, and their macroscopic level manifestations; cancer, Down's Syndrome, and Acquired Immunodeficiency Syndrome, respectively.

Science educators have recognised the importance of the cell theory in that virtually all students are exposed to instruction in the cell and cell division at some time in their secondary schooling. In British Columbia, the concepts
are first presented in the grade 10 general science course. While some students may receive instruction in the concept of cell in grade 6 or 7 (for example, the Elementary Science Study unit, Small Things), elementary science curriculum developers have been predominantly concerned with the macroscopic concept of growth. Thus, the Elementary Science Study program presents units on plant growth at grades 1, 2, 4, and 5; the Teaching Primary Science program at grade 3; and the Examining Your Environment program at grades 6 and 7.

Based on the prevalence of these topics in science curricula and students' repeated exposure to them, one might expect that students at the end of grade 10 will have conceptions of the cell and growth resembling closely those presented in the materials. Although there is rather little research investigating the extent to which this expectation is being met, the studies that do exist suggest that the majority of students hold conceptions different from the scientific concepts as they are represented in the materials. (Hackling and Treagust, 1982; Marek, 1984; Okeke and Wood-Robinson, 1980).

Evidence also exists with respect to the concepts of growth and life to suggest that students' conceptions often do not reflect those of the instructional materials to which they have been exposed (Brumby, 1981; Lawson, 1988; Russell and Watt, 1989; Smith and Anderson, 1984; Smith and Lott,

Based on an examination of curricular materials, there are a number of implicit assumptions evident in science curricula concerning students' existing knowledge and the way in which they learn new content. These may account for some or all of the student difficulties identified above. These assumptions, related specifically to growth and the cell, include the following:

1. The student has no personal conceptions of the structure and growth of living things prior to instruction.

2. The student will incorporate the conceptions presented in the materials into his cognitive structure without alteration or modification.

3. The new conceptions will persist over time and will be resistant to change.

4. The student will hold a conception of cell differentiation.

5. The student will link his conceptions of the cell, mitosis, and differentiation to the process of growth in plants and other organisms.

Questions related to students' prior knowledge and the effects of instruction upon it (assumptions 1-3) have been the subject of extensive investigation in science education. Based on a "constructivist epistemology" (Driver, 1982,
1989) which sees "learners (as) actively generating meaning from experience" (Driver and Erickson, 1983), researchers have come to realize the importance of the knowledge a student brings to the learning situation. This prior knowledge has often been found to be the source of "alternative conceptions" which are frequently at variance with the "scientific conceptions" presented in science curricula.

While it has been traditionally thought that these alternative conceptions, if they exist at all, can be easily displaced by the scientific conceptions presented by the teacher, Gilbert, Osborne and Fensham (1982) argue that this may not be the case. They conjecture that students may reject the scientific conception completely, learn it as something relevant for examinations but not their every day world view, or amalgamate the two conceptions into something resembling neither. Any of these possibilities may be diagnosed in terms of learning difficulties.

Assumptions 4 and 5 are related loosely to what Fisher (1984) refers to as "errors of omission" resulting in student misconceptions in biology. While she relates these errors strictly to relationships between concepts, I include in this category also the omission of entire concepts. Schaefer (1979), Okeke and Wood-Robinson (1980), Stewart and Dale (1981), Hackling and Treagust (1982), and Stavy, Eisen and Yaakobi (1985) have all identified omissions in
instruction which may complicate students' attempts at coming to scientific conceptions of growth and the cell.

This study is based on my contention that sufficient evidence exists to warrant the investigation of the validity of these assumptions. If they are found to be invalid, the data provided by the present study could provide the foundation for the development of new conceptual and instructional approaches which could assist teachers in helping students with the learning difficulties they are encountering in this content area.

This thesis is organized into 6 chapters. This first chapter serves as an introduction and overview of the study. Chapter 2 presents the literature relevant to the study. It includes a review of research examining students' conceptions in biology and students' learning difficulties with respect to growth and the cell. It also outlines the psychological and educational contexts of the study.

Chapter 3 presents the methods and procedures used in this research. It discusses the development of the interview protocols and their administration. The chapter also discusses the student sample for the study.

The results of the study with respect to student conceptions of growth and the cell are presented in Chapter 4. This chapter also discusses in detail the method of data analysis.
Chapter 5 presents results which focus on changes in students' conceptions of growth and the cell after instruction on these topics.

The conclusions, educational implications, and recommendations for further research are presented in Chapter 6.

1.1 Definition of Terms

Conception: is defined as an idea or belief elicited from an individual in propositional format to respond to a problem situation or question in an interview. Each of an individual's expressions in the interview transcript that can be construed as evidence of his/her underlying beliefs regarding the problem situation or question is summarised in the form of a statement in the individual's own words where possible. This notion of a conception is the basic unit of analysis in this study.

Scientific conception: a conception held by an individual regarding a phenomenon which is similar to the concept regarding that phenomenon as it is displayed by curricular materials or by the current disciplinary knowledge in the relevant field. Scientific conceptions may be constructed by the individual on the basis of instruction in a formal setting or on the basis of previous physical and linguistic experience.
Alternative conception: a conception held by an individual regarding a phenomenon which differs from the concept regarding that phenomenon as it is displayed by curricular materials of the current disciplinary knowledge in the relevant field. Alternative conceptions are often constructed by individuals spontaneously as a result of their everyday physical and linguistic experience but they may also be constructed on the basis of instruction in a formal setting.

Conceptual inventory: a set of an individual's conceptions, both scientific and alternative, identified in an interview and organised into a number of content-oriented categories.

Cell: the fundamental structural and functional unit of living matter, bounded by a plasma membrane.

Growth: The process of developmental change in an organism from an immature to a mature form. Growth is the result of cell division, enlargement, and differentiation at the microscopic level.

1.2 Statement of the Problem

Science curricula and instruction have usually ignored students' alternative conceptions (Fensham, 1983). Developers and teachers have assumed that the learner either has no prior knowledge regarding the relevant topic prior to
instruction or that if such knowledge exists, that it can easily be replaced by science teaching. Gilbert, Osborne, and Fensham (1982) refer to these as the "tabula rasa" and "teacher dominance" assumptions, respectively. These assumptions have been investigated directly and indirectly with respect to an extensive range of concepts in physics and chemistry and have been found to be invalid (see Driver and Erickson, 1983; and Gilbert and Watts, 1983, for extensive reviews of this issue). Research in biology education has been less profuse but the conclusion appears to be the same (see Chapter 2). Students have been found to possess a wide range of alternative conceptions with respect to the majority of concepts studied and many of these have been found to persist in spite of instruction.

This persistence has typically been viewed as "incorrect answers" on the part of the student as a result of errors made while learning a concept. It is suggested that the persistence is more likely the result of conceptual confusion generated in the student as a result of conflict between his alternative conceptions and the scientific conceptions encountered during instruction.

Growth is a phenomenon with which most children can be expected to have some experience prior to instruction. The possession of alternative conceptions constructed on the basis of this experience may result in difficulties for the student when encountering the concept of growth in a school
class at the elementary level. Furthermore, persistent alternative conceptions or ones developed during instruction may result in further difficulties when the student confronts the cell concept in secondary science.

The first aim of this study was to identify students' conceptions of growth and the cell prior to instruction at both the elementary and secondary science levels.

Different teaching strategies and materials will be called for depending on whether students maintain their alternative conceptions in a complete form after instruction, replace them wholesale with the scientific conceptions, or construct an amalgam of both, which is in essence a new alternative conception.

The second aim of this study was therefore to determine whether students' conceptions of growth and the cell change after instruction and to examine the nature of this change if it occurs.

Based on my teaching experience and knowledge of the curriculum it was conjectured that some of the potential learning difficulties may stem from two additional factors. Failure to expose students to the concept of cell differentiation leaves them with only their own experience on which to base their interpretation of this important component of the phenomenon of growth. Failure to make explicit that the phenomenon of growth at the macroscopic level is a manifestation of cell division, growth, and
differentiation at the microscopic level may result in the students not recognizing this central relationship in biology. Both failures are likely to result in conceptual confusion and may well be responsible for the creation of alternative conceptions with respect to growth, and other concepts such as reproduction, development, and genetics.

Therefore, the third aim of this study was to identify whether students hold conceptions of differentiation at both the elementary and secondary levels. It was also to determine if they link growth at the macroscopic level with cell division, growth, and differentiation after general science instruction up to the grade eleven level.

1.3 Research Questions

The following are the specific research questions addressed by this study based on the three general aims outlined above.

1. What are students' conceptions of growth in plants and animals in grades 3, 5, 7, and 10?

2. What are students' conceptions of the cell in grade 10?

3. Do the grade 3 students' conceptions of growth change after instruction in science?

4. Do the grade 10 students' conceptions of growth and the cell change after instruction in science?
1.4 Overview of Methods the of Study

This study was conducted in two phases. The first phase addressed research questions 1 and 3, that is, student conceptions and change at the elementary level. The second phase addressed questions 1, 2, and 4, related to student conceptions and change at the secondary science level.

As part of the first phase of this study a semi-structured interview protocol and tasks based on an analysis of the concept of growth was developed. This protocol and its associated tasks will henceforth be referred to as the Growth Protocol.

Eleven students, ages 8-10 (grade 3), were individually interviewed using the Growth Protocol prior to and after instruction in the concept of growth in plants. Eight of these students were interviewed again two years later (grade 5) using the Growth Protocol. The interviews were tape recorded. The analysis of the data involved in all cases the construction of conceptual inventories for each student identifying their alternative conceptions. The conceptions in the students' inventories were then organised into categories and compared and analysed for changes. This provided the data with which to address research question 3.

A further ten students in each of grades 5 and 7 in a different school were interviewed using the Growth Protocol. Conceptual inventories were constructed for each student and together with the inventories of the grade
3 students above provided in part the data to address research question 1.

For the second phase of the study, a semi-structured interview protocol and tasks based on an analysis of the concept of the cell were developed. This protocol and tasks will henceforth be referred to as the Cell Protocol. Five students from each of four grade 10 classes were interviewed prior to and after a unit of instruction on the cell. The interviews were tape recorded and conceptual inventories were constructed for each student, identifying alternative conceptions. The conceptions in the students' inventories were then organised into categories and compared and analysed for changes. This phase provided the data to address research question 1 at the grade 10 level and research questions 2 and 4.

1.5 Delimitation of the Study

This study was limited to investigating students conceptions with respect to growth at the elementary science level and growth and the cell at the secondary science level. There are other concepts which are closely related to these which were considered only insofar as they were components of students' conceptions related to growth and the cell. For example, the processes of meiosis and fertilization and the associated concept of reproduction are treated immediately after mitosis in secondary science
curricula and could be expected to have some influence on the conceptions in question.

One of the reasons for not investigating students' conceptions beyond the grade 10 level is that it will likely become progressively more difficult to relate specific alternative conceptions to learning difficulties as the subject matter becomes more complex. The other is that science at the grade 10 level is for many students the last formal instructional exposure they receive in science.

This study was primarily descriptive and exploratory in nature. As such, it was designed to yield information regarding a wide range of potential sources of learning difficulties experienced with respect to the concepts of concern. This will allow teachers and curriculum developers to address the concepts as a whole rather than simply modifying single elements of instruction (such as adding the scientific conception of differentiation to existing strategies). While in some cases the latter may be effective in dealing with specific difficulties, its effects may often be obscured by other problems which affect the element.

This study does not test any specific hypotheses with respect to the prevalence of specific alternative conceptions in the general student population. It does not advance any hypotheses related to the effects of instruction on such conceptions. This research was aimed at providing a wide range of information regarding students conceptions of
growth and the cell on the basis of which decisions can be made regarding the creation of more specific hypotheses. The information necessary for making these decisions does not currently exist.

The methodology used in this study is a modified version of Piaget's (1969) "clinical method". The instruments used are two semi-structured interview protocols which allow for the elaboration and clarification of ideas by the student in response to the probing questions from the interviewer. Considerations of the validity and reliability of this technique are addressed in Chapter 3.

1.6 Justification of the Study

The research study outlined above makes an important contribution to inquiry in the field of science education for the following reasons:

1. The concepts of growth and the cell are central to modern biology.

2. The concept of growth is considered, often more than once, in most North American elementary science curricula and the concept of cell is considered in virtually all North American secondary science curricula.

3. Research has demonstrated that students have difficulties with these concepts yet few studies have been directed at investigating the sources of
these difficulties.

4. These concepts are very likely critical barriers (Hawkins, 1978) in that student difficulties with the cell and growth may lead to further difficulties in genetics, biochemistry and physiology.

5. Knowledge regarding the sources of learning difficulties is central to the development of curricula and teachers' attitudes aimed at facilitating students' understandings of the concepts of growth and the cell.
CHAPTER TWO

REVIEW OF THE LITERATURE

2.0 Introduction

The literature review for this study is directed towards three principal areas:

1. A review of selected research investigating students' conceptions in biology.
2. The general psychological context of the study.
3. The educational context in which the findings of the study can be applied.

With respect to the first area, studies of students' understanding of biological concepts are reviewed with the aim of (1) demonstrating the existence of alternative conceptions which may affect their understanding of growth and the cell, and (2) demonstrating that students do in fact encounter learning difficulties with these concepts.

Regarding the psychological context of this study, a general overview of the constructivist approach to learning is presented. Also, Posner, Strike, Hewson, and Gertzog's
"Theory of Conceptual Change" is summarized and discussed. This is the psychological model adapted for this research.

In the final section, the pedagogical implications of this type of research are discussed in terms of curriculum development and teaching strategies.

2.1 Students' Alternative Conceptions in Biology

The purpose of this section is to present an overview of research investigating children's alternative conceptions in biology. The review is restricted to those studies which have potential implications for children's conceptions of growth and the cell.

One of the most extensively investigated concepts in biology is the concept of "life". This concept is pertinent to the present study in that growth, development and the possession of cells are primary criteria for ascribing life to an object. Its central importance in biology is obvious and is reflected by the persistence of the concept as one of concern in early studies relating children's ideas to Piagetian stages and later work investigating the substance of the actual ideas.

Piaget (1969) used the term "animism" to describe the mental phenomena in children resulting in ascribing life and life-like qualities to inanimate objects. He suggested that animism arises through an inability on the part of the child...
to distinguish a boundary between herself and the objects in her surroundings, that is, seeing objects as extensions of herself. Piaget (1969) suggested four phases through which children move with respect to the concept of life:

1. Being alive is anything active in any way.
2. Life is assimilated to movement.
3. Movement comes to be seen as spontaneous, or independent.
4. Adult view (life restricted to plants and animals).

While the stages were not linked to a specific age, the sequence was seen as unmodifiable and necessary.

Safier (1964) investigated children's ideas of life with a view towards validating Piaget's stages. Based on interviews with boys from three age groups, she identified an overall decrease in the number of life and death ideas ascribed by children to inanimate objects with increasing age. Using the students' responses, she was able to loosely correlate the three age groups to a modification of the stage theory.

Angus (1981) also investigated children's ideas regarding life from the perspective of the stage theory. Fifty interviews were conducted with children aged 6-8 years in which they were asked whether a variety of items were living or non-living. Trees were seen as non-living by 29 percent of the sample, potatoes by 40 percent, carrots by 39 percent, and grass by 32 percent. Also, a variety of non-
living objects were identified as living. When asked about their primary reason for identifying an object as living, children gave movement as the predominant response.

Stephans (1985) found that older children (aged 10-11) correctly identified worms, trees, leaves, and flowers as living. There were particular difficulties in this sample of 30 students with inanimate objects, however. Students identifying lightning, wind and volcanoes as being alive totalled 82, 79, and 76 percent of the sample, respectively. Caution must be used in interpreting these result since it is not clear from Angus' data whether the students where using the term "life" metaphorically or whether they were actually refering to the organic definition. Again, in asking the students what it meant to be alive, the majority responded with movement as the prime determinant.

A number of researchers have moved away from the stage theory research to look more closely at childrens actual ideas regarding life. I believe these studies resulted in part from evidence suggesting that many of the older students which the stage theory predicts should reach the adult stage, in fact, do not. The research extends the usefulness of the earlier studies in that it attempts to address the question of why children identify objects as living and non-living.

Tamir, Gal-Choppin, and Nussinovitz (1981) designed a study to investigate not only which objects students
identified as living and non-living but also the criteria they used for their decisions. Three hundred and ninety-four students aged 8-15 participated in a classification test and later answered questions on a questionnaire. Identification was found to be better than 80 percent correct for most items, with the exception of embryos (56.3% correct), seeds (60.8% correct), and eggs (51.8% correct). Growth and development were used as criteria for life in animals by only 6.7 percent of the students, for life in plants 37.8 percent, and in embryos 20.2 percent.

In the second part of their study, of 83 students aged 10-15, only 45 percent understood that it was impossible for a living organism to develop from an inanimate object, 36 percent realized that living organisms originate from other living organisms, and 19 percent held the idea that living organisms could actually originate from non-living objects.

Traditionally, one might expect that students' understanding of life and the criteria for ascribing it to objects would become clearly defined as a result of instruction in biology. The evidence currently available, however, does not support this assumption.

Brumby (1981) examined how 150 first-year students enrolled in the Faculty of Medicine at Monash University, Australia, characterised living organisms and discriminated between alive, dead, and non-living. Of 266 responses to the question "Why do you believe that fire is not alive", only
18 percent included references to cells. Only 16 percent included references to the traditional "seven characteristics of living organisms"; growth, reproduction, respiration, nutrition, excretion, irritability, and locomotion. Responses to a question related to a rock being alive, dead, or non-living included 11 percent of the sample invoking cells and 26 percent invoking the "seven characteristics".

This study was essentially replicated with first year biology classes at a British university (Brumby, 1982). The results were similar to those found with the Australian students. The majority of responses did not contain a scientific explanation of life; rather, "movement" dominated the answers. Brumby draws special attention to the fact that few of the students included DNA as a self-replicating molecule in their responses, especially as the Australian group had just completed a unit on DNA. This is not particularly surprising in view of the number of cell and growth responses given. If the students do not relate these basic concepts to their conception of life, it is highly unlikely that they will relate the more complex and abstract concept of DNA to it. Brumby (1981) draws much the same conclusion in that "Their difficulty is not in 'knowing' but in being able to 'use' their knowledge, out of the context of schools, exams, and textbooks".

Brumby's studies essentially support the suggestion
that alternative conceptions, such as movement being a sufficient criterion for ascribing life to an object, may be present at all age levels and do not simply represent stages of development. Furthermore, her work presents the possibility that these alternative conceptions may interfere with instruction, in this case rendering concepts such as growth and the cell as secondary or even superfluous to an understanding of life.

Several studies in a number of other areas in biology support these suggestions. Kargbo, Hobbs and Erickson (1980) found no developmental trends in a wide range of beliefs expressed by 7-13 year old children with respect to the concept of heredity. They identified four alternative frameworks in the types of explanations the children used in predicting the occurrence of traits in offspring. The most predominant of these (16 of 32 children) was the "naturalistic" explanation which invoked life cycle, nature, sex resemblance to parent, or motherhood in the explanation (eg. "The man is tall and the boy is going to be a man, so he will be tall. The mother is short, and she is a girl, so she will be short", Kargbo et al., 1980, p. 144).

Deadman and Kelly (1978) identified a similar naturalistic framework in boys' explanations of heredity within the context of evolution. This framework, also referred to as Lamarckian with respect to the process of evolution, was singularly predominant in explanations
related to the evolution concept. Students' conceptions identified within this framework are "related to the 'nature', i.e. characteristics and feelings of organisms, as when pupils referred to 'needs' or 'wants' of an animal or some undefined internal force within the animal" (Deadman and Kelly, 1978, p. 12).

Brumby (1979) identified this naturalistic or Lamarckian framework as being predominant in the explanations of 63 first year university students, most of whom had a strong high-school background in biology. The majority of students were found to believe that "organisms 'can gradually adapt to a change in the environment' if they 'need to' and hence 'evolve'". She goes on to suggest that these pre-existing beliefs may act as a barrier to the formal learning of Darwinian evolution.

In a large sample of Israeli highschool (N=349) and university (N=48) students, Jungwirth (1975) found that more than 50 percent of the students, at both levels, selected items on a test which represented this naturalistic or, in his terms, "cart before the horse" interpretation of evolution.

There is currently no evidence to suggest that the naturalistic framework is an important framework with respect to the concept of growth. The possibility exists however, in view of a quote from a study by Danziger and Sharp (1958) attempting to identify stages in the
development of children's ideas about growth and movement:

Investigator -- What makes a dog grow?
Student (age 5) -- ...Because he wants to get bigger.

(p. 201)

A series of studies investigating students' understanding of the concept of photosynthesis also holds implications for this study. A recurrent alternative conception identified in these studies is that soil is the food for plants (Wandersee, 1983; Smith and Anderson, 1984; Smith and Lott, 1983).

Wandersee (1983) examined students' understanding of photosynthesis in a cross-age study utilising 1405 subjects. One of the questions asked students to predict whether the weight of soil in a container would increase, decrease, or stay the same after a plant had been grown in it for 5 years. Fifty-two percent of the 5th graders, 56 percent of the 6th graders, 35 percent of 11th graders, and 19 percent of college students stated that the weight would either increase or decrease substantially. In explaining their answers, 13 percent of the students at the lower grade levels stated that the weight of the soil would decrease because soil is the plant's food. In the higher grade levels, 21 percent offered this explanation. Examples of the written responses to the question of why the soil lost weight included the following (Wandersee, 1983):

Scott (Grade 5) -- Because the soil is the plant's food and without it a plant couldn't live.
Vance (Grade 8) -- Because the plant ate minerals (food) from the soil. That's why the plant got big.

Jackie (College) - Because when the plant grew it was taking all its food out of the soil. The roots were also growing and taking up much more room. (p. 446)

Simpson and Arnold (1982) suggested that this difficulty may be related to children's conceptions of food. Students in their study did not classify starch or leaves as food and the authors suggested that part of the students' ideas was likely to be based on the everyday meaning of food rather than the scientific one.

Evidence for this view is provided by Stavy, Eisen, and Yaakobi (1985) who found 33, 13-15 year old students to be "with no exception, ...surprised and startled" by the question "From which chemical elements is your body built". They concluded that the difficulties students had in conceiving of the human body as a chemical substance might in part be responsible for their inability to identify the three major elements of which the body is composed even after explicit instruction.

This alternative conception of food may also be present in another context, that of animals. The following quote is again from Danziger and Sharp (1958) who were interested only in "a purely formal categorization (or set of stages) with no reference to the specific content of the child's replies":

Student (age 9) -- ...eating makes a dog grow.
Investigator -- How does eating make him grow?
Student -- Fills him up and makes him bigger-higher and fatter.
Investigator -- How?
Student -- ...it starts to push him out and then up. (p. 201)

Alternative conceptions of soil as food and of food itself are by no means the only ones found with respect to photosynthesis. Wandersee (1983) identified a further 30 of what he refers to as "misconceptions". His sample of written responses also contains statements which appear to reflect conceptions which could be classified within the naturalistic framework discussed above. For example, the following is an explanation by a student of why he thought soil would lose weight:

Steve (Grade 5) -- Because when the plant grew it had to have room so it had to lose it. (p. 446)

Lawson (1988) conducted interviews with 3 children (ages 6, 9, and 10) in which he asked them questions regarding a range of biological concepts including photosynthesis and growth. While he argues "that within the biological sciences, at least, many students will not come to class with well-formulated alternative conceptions (p. 197)", his results indicate at least one clear exception. Two of the students identified water as food for plants and suggested that water is somehow responsible for their growth. There is also some evidence to suggest that one of the students held a conception in which plants make food from water and possibly soil:
Investigator -- How do plants get their food?
Bob (age 9) -- They make it from water.
Investigator -- Do they use anything else?
Bob -- Well, soil. But I don't know if they make it from soil.

Russell and Watt (1989) investigated conceptions of growth in 61 primary school children (ages 5-11). The alternative conception that soil is the food for plants was identified in a number of students interviewed in this study. The greater majority of children, 90 percent, suggested that the intake of water was the primary factor responsible for the growth of plants. A number of students held the conception that all the food necessary for a plant to grow is already present in the seed.

After identifying these alternative conceptions, the authors designed an intervention which encouraged teachers to change their orientation from traditional materials to using the children's ideas as a starting point for classroom investigations. While cautious in their conclusions, these authors identified an increase in the reference to light in students' conceptions as well as an increase in the number of conditions suggested by students as being necessary for growth. They also suggest that after the intervention, students conceptions more frequently included the notion of materials being incorporated and reorganized in the plant.

It is possible from the discussion above to outline some of the difficulties students may face in attempting to come to a scientific conception of growth. Formed on the
basis of their own experience, students may approach
instruction with a conception of life based on the criterion
of motion. They must then confront the idea that some moving
things are not alive and some non-moving things are,
especially plants. The criteria for this new conception of
life are not visible nor are they likely to be within the
students' immediate experience (eg. cell).

Children must then conclude from a series of brief and
artificial classroom experiences that a number of
environmental factors and elements are responsible for
growth rather than simply the fact that "the plant wants to
grow". Also, the plant does not simply "fill up" with soil
and water but changes them in some way in order to become
bigger. Coming to this latter conception, students must
again alter their conception of life in that living things
are actually made up of non-living (eg. water) substances.

These ideas must then be transferred to other living
things such as humans, making the appropriate modifications
along the way. The cell, again encountered in a brief and
artificial situation, must then become the overall unifying
concept into which these ideas must be incorporated.

The construction above is hypothetical. It is my
purpose to uncover the extent to which a small number of
students at different age levels have developed these
conceptions.

The scenario above introduces another possible source
of difficulty for students apart from their alternative conceptions, that is, the omission of important concepts or relationships from instruction, what Fisher (1984) refers to as errors of omission.

Schaefer (1979), Okeke and Wood-Robinson (1980), and Hackling and Treagust (1982) have all commented on the conspicuous absence of the concept of cell differentiation in science curricula, yet the consequences of its omission with respect to students' conceptions of growth and the cell have not been investigated. Schaefer (1979) investigated the development of the concept of growth (not limited to organic growth) by having individuals from a wide range of age groups and levels of education construct chains of associations for the concept. The percentage of associations for the biological category of differentiation were found to be relatively constant across the sample at 17 ± 3 percent. He suggests that this relatively low percentage "is probably due to the conceptual separation of growth and differentiation in some textbooks", implying a failure on the part of instruction to conceptually link the concepts.

The difficulties which students experienced with food discussed above may also in part be due to an error of omission, that is, explicitly linking the discussion of the chemical nature of food substances to students' everyday understanding of food.

Fisher (1984) suggested that students' failure to
perceive appropriate relationships between concepts such as the Punnett square and meiosis account for a large pool of their "errors" in genetics.

Stewart and Dale (1981), addressing this problem empirically found that their "data indicate that the students' primary problems were concerned with how meiosis and the Mendelian genetics of the cross problems could be brought together meaningfully." They suggest that the source of this problem lies not with the students, rather:

During instruction more attention needs to be given to being explicit in helping students see how different parts of a course, unit, or lesson are conceptually related. Instructors should not assume that most students will structure in the way they intend them to. (Stewart and Dale, 1981, p. 63)

Stewart (1985), in a subsequent paper goes on to argue:

In order for students to have a greater understanding of genetics, major revisions will have to be made in instruction to make its conceptual organization more explicit. (Stewart, 1985, p. 14)

I believe that both instructors and curricular materials often assume that students will relate not only parts of a course, but also related concepts, such as growth and the cell, and then transfer these concepts across contexts, such as from plant to animal.

This section has provided evidence of students' alternative conceptions in areas related to growth and the cell which may contribute to learning difficulties. The following section addresses student learning difficulties
that have been identified with respect to the concepts of growth and the cell.

2.2 Students' Learning Difficulties with the Concepts Growth and the Cell

Okeke and Wood-Robinson (1980) investigated students' understanding of three biological concepts, reproduction, transport, and growth. The sample was composed of 120 Nigerian students between the ages of 16 and 18. Growth was selected for investigation because an understanding of it was implied in many areas of their course of study, "Pupils must therefore put together and synthesize their ideas on growth from many diverse parts of their work" (Okeke and Wood-Robinson, 1980). A similar argument is applicable to the secondary science curriculum in British Columbia.

In their study "growth" was broken down into seven separate conceptual areas, the students' knowledge of which was assessed using an interview schedule. The responses pertinent to each conceptual area were then scored on a five point scale. Five was described as answers which included all the relevant sub-concepts and relationships as well as generalizations or applications and explanations appropriate at the School Certificate Level, while the low end of the scale (one) included answers which showed no grasp of any of the relevant sub-ideas or "I don't know" answers.

Over 16 percent of the students scored (1) for the conceptual areas of "the role of cell differentiation" and
"the factors affecting growth" while over 30 percent scored (1) for "rates of growth in relation to the developmental stages of an organism" and "the function of meristematic cells in the growth patterns of plants". The mean scores for the areas "growth as a characteristic of living organisms" and the "mechanism of growth in terms of cell multiplication" were both 3.2. The overall mean score for the concept of growth was 2.7, placing somewhere between (2) - answers which included some of the relevant sub-ideas, and (3) - answers including all sub-ideas, but no explanations or generalizations.

The authors also found that "a large number of pupils revealed total confusion between cell division, enlargement, and cell differentiation." Over 18 percent of the students suggested that cells get progressively smaller as they pass through division and about the same proportion had no ideas regarding the origins of the different cells in a multicellular animal.

Marek (1984) investigated students' understanding of a number of biological concepts including the cell using a paper and pencil instrument. The subjects of the study were 60 tenth-grade students who had completed a biology course utilizing Modern Biology as the primary curriculum. Only 15.8 percent of the students were scored as demonstrating a sound understanding of the cell while 21 percent were scored as exhibiting a specific misunderstanding of the concept.
While Marek (1984) does not extensively discuss the specific misunderstandings, he does list four typical responses. These are: "non-living stores protein"; "non-living cells"; "living things are moving", and "organic materials are made of cells". Although these statements are too brief to draw any firm conclusions, it is interesting to note that all of the "misunderstandings" involve the concept of life and one states directly the alternative conception of movement as discussed in Section 2.1.

A third study by Hackling and Treagust (1982) considered the propositions these authors thought necessary for a student's understanding of the concept of heredity. Among these, 9 were specifically related to growth and the cell. Forty-eight students having completed a year 10 (15 years old) unit on genetics were interviewed using a semi-structured protocol and the ideas of the students related to the specific propositions were then scored as either exhibiting comprehension, recall, lack of knowledge, or misunderstanding.

Only 48 percent of the students comprehended that growth occurs by a process of cell division. No students comprehended and only 23 percent could recall that mitosis was associated with growth. Comprehension for the idea "environmental factors influence growth" was 56 percent, "mitosis is a form of cell division" was 38 percent, and "each daughter cell has the same genes and chromosomes as
the original cell" was 11 percent.

Sixty-five percent of the students believed that each cell in the body had a different set of genes and only 2 percent comprehended (0% recall, 98% lack of knowledge) that all body cells have the same genes because they all came from the zygote by mitosis.

These three studies strongly suggest that secondary science students experience considerable difficulties with the concepts of growth and cell even after explicit instruction in the latter. There is some evidence to suggest that this may involve alternative conceptions and also "errors of omission" in terms of both the concept of differentiation and linking the concept of growth to that of cell. This study addresses these possibilities more directly.

Two other studies (Pella and Strauss, 1969; Billeh and Pella, 1970) should be noted here, although their significance is difficult to determine. They are grade placement studies aimed at teaching the cell to the level of DNA replication and transcription at the elementary level.

Pella and Strauss (1969) used paper and pencil tests, which were read to students, in order to determine whether they could comprehend, generalize, and apply a series of 11 subconcepts of the cell taught using a unit prepared, it is assumed, by the investigators. Students in Grades 2 through 6 were used although the number of students per grade nor
the total sample is given.

The criteria for accepting a concept for inclusion in a given grade was (1) that the mean score earned by pupils in a given grade had to be significantly higher than guessing (no level of significance given) and (2) a minimum of 50 percent of the pupils in a given grade had to earn a score of 65 percent or better of the maximum score. How the scores were determined is not stated nor is the content of the tests.

The list of results is detailed but perhaps the most significant results were that the subconcepts "cells have a basic structure" could not be taught to the comprehension level at any grade and "cells cannot grow to indefinite size" could not be taught to the application level at any grade.

Billeh and Pella (1970) used the same tests and lesson plans, translated into Arabic, to compare the achievement of Jordanian and American children with respect to the cell concept as defined in Pella and Strauss (1969). American students had significantly higher scores for some concepts, Jordanians for others, and some concepts showed no significant differences. Billeh and Pella (1970) therefore concluded that "culture does not seem to be a factor in learning the concepts used in this study".
2.3 The Psychological Context of the Study

2.3.1 Introduction

Osborne and Wittrock (1985) identified four major perspectives in educational psychology which have had a major impact on both science education and science education research:

1. The developmental tradition - aimed at determining at what age levels the learning of various concepts by children can be expected to be successful.

2. The behaviourist tradition - emphasising reinforcement, and through instruction building increasingly complex skills and behaviour.

3. The constructivist tradition - which views the learner's existing knowledge as central to the way he interprets experience and constructs meaning.

4. The information-processing tradition - which is concerned with generating "component oriented, often computer based" models of human learning. (Osborne and Wittrock, 1985)

The majority of recent studies of learning in biology and physical science content areas (see Driver and Erickson, 1983, and Gilbert and Watts, 1983, for extensive reviews of research in the latter) have been primarily problem driven, that is, oriented towards considerations of student learning in the school environment. Most of these studies do, however, exhibit a common perspective in terms of either their implicit or explicit view of learning, one which is reflected by the constructivist tradition.

Driver and Erickson (1983) have attempted to explicate the common assumptions of this perspective by outlining the
argument used by researchers to justify their program:

Empirical Premise One: Many students have constructed from previous physical and linguistic experience frameworks which can be used to interpret some of the natural phenomena which they study formally in school science classes;

Empirical Premise Two: These student frameworks often result in conceptual confusion as they lead to different predictions and explanations from those frameworks sanctioned by school science;

Empirical Premise Three: Well-planned instruction employing teaching strategies which take account of student frameworks will result in the development of frameworks that conform more closely to school science;

Value Premise One: One should conduct research which will lead to a better understanding of school science by students.

Conclusion: We ought to engage in research endeavours which will uncover student frameworks, investigate the ways in which they interact with instructional experiences and utilise this knowledge in the development of teaching programmes. (Driver and Erickson, 1983)

Gilbert and Swift (1985), in an analysis of the shift in influence of what they call the alternative conceptions movement (ACM) over the Piagetian School (PS) in science education research, have further attempted to clarify the assumptions common to the constructivist tradition which underlies the ACM:

1. The world is real.
2. All observations are theory-laden.
3. Individuals use personally appealing explanatory hypotheses to cope with events in their environment.
4. The individual tests these hypotheses through interaction with reality against personally appealing criteria.
5. Reality provides guidance as to the adequacy of
these hypotheses so tested.

6. When hypotheses are judged inadequate by such testing, either the hypotheses or the test criteria by which they were judged are modified or replaced. (p. 689)

The basic element of Ausubel's (1968) theory of learning is best illustrated by his now famous dictum:

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, 1968, p. vi)

The most important elements with respect to learning, from problem oriented, philosophical, and theory oriented perspectives, appear therefore to be the individual's prior knowledge constructed on the basis of experience, and how this prior knowledge interacts with new experience. The purpose of this study was to investigate the extent to which this prior knowledge has been constructed and the way in which it changes over time for the concepts of organic growth and the biological cell.

2.3.2 Prior Knowledge

There is general agreement among researchers investigating individuals' knowledge that it can be accessed by their actions and their verbal responses in particular problem settings (Driver and Erickson, 1983; Gilbert and Watts, 1983).

The characterization of this knowledge is not as clear cut, however. Individuals' knowledge has alternatively been referred to as conceptual frameworks (Driver and Erickson,
It is not my purpose in this section to synthesize a common nomenclature nor to speculate on the underlying epistemological commitments of the above researchers. Rather, I wish to clarify how students' knowledge will be characterized in this study.

An individual's knowledge regarding a phenomenon will be described in terms of conceptions associated with that phenomenon and represent for that individual a reflection of how the world really is (Hewson, 1980). These conceptions are seen as being based on the personalised theorizing and hypothesising of the individual (Gilbert and Watts, 1983) resulting from experience with phenomena. The conceptions may be linked to other conceptions in a complex network referred to by Posner, Strike, Hewson, and Gertzog (1982) as the individual's "conceptual ecology".

Conceptions, whether they are held prior to or after instruction, are thus viewed as personally viable constructions of the phenomena under consideration. If they are congruent with formal scientific constructions regarding
the phenomena, I will refer to them as scientific conceptions, if they are not, they will be referred to as alternative conceptions. Thus, persons may well have constructed scientific conceptions on the basis of their experiences prior to instruction, and may also construct alternative conceptions as a result of instruction.

An example of both of these situations can be found in a case study of students' conceptions of plants conducted by Smith and Anderson (1984). Prior to instruction, they found 79 percent of the students holding the scientific conception "plants need light to live and grow". After participating in a series of lessons on plants which included observing grass over a period of time under both light and dark conditions (a common elementary school experiment) they unanimously asserted that plants do not need light to live and grow. Smith and Anderson (1984) viewed the development of this alternative conception as being the result of observations by the students that the grass in the dark was "light green", "yellow", "weaker", and "growing in all directions", but nevertheless alive and growing. A number of students described the plants in the light as simply being "healthier" and one suggested "light is like vitamins for the plant".

2.3.3 Conceptual Change

The second aspect of learning of concern in this study
is that of conceptual change, especially as it relates to instruction. Posner, Strike, Hewson and Gertzog (1982) have developed a model of conceptual change, based in part on developments in the philosophy of science, which attempts to account for the ways in which an individual's knowledge interacts with new experience (see also P. Hewson, 1981; Posner, 1983).

Hewson (1982) suggests four possibilities for the fate of a new conception as it is encountered by the individual: it may be rejected outright, it may be rotely memorized and not reconciled with prior conceptions, it may replace a prior conception and be reconciled with remaining conceptions (accommodation or conceptual exchange) or it may be reconciled with existing conceptions (assimilation or conceptual capture).

The model, and the research it has generated (Hewson, 1982; M. Hewson, 1981, Hewson and Hewson, 1981) has concentrated mainly on accommodation in that the authors are primarily interested in two issues: the conditions under which central concepts come to be replaced by others, and the features of the conceptual structures which govern the selection of new concepts (Posner et al., 1982).

Four conditions are seen as essential if accommodation is to occur:

1. There must be dissatisfaction with the existing conceptions.
2. A new conception must be minimally understood or "intelligible".


In order for assimilation to occur, the same four conditions apply, with the addition of one further condition -- that the new conception be reconcilable with the prior conception. Whether reconciliation occurs depends on the strength of the inferential links between the concepts, their consistency and the condition that they are not contradictory (Hewson, 1982).

If the new conceptions meet these criteria, factors of the individual's conceptual ecology will figure predominantly in the direction accommodation or assimilation will take. These features include the individual's epistemological commitments, (explanatory ideals and general views about knowledge), metaphysical beliefs and concepts regarding science, past experience, and knowledge in other areas.

The fruitfulness of viewing conceptual change from the perspective of a relationship between features of the conceptual ecology and the conditions for the accommodation and assimilation of new concepts has been demonstrated by Hewson (1982). In a series of interviews with a graduate physics student, he identified the student as holding a firm Newtonian commitment to a mechanistic view of the world even
after exposure to Einstein's Special Theory of Relativity (STR). In discussing two of the propositions of STR that run counter to experience, the slowing of moving clocks (time dilation) and the shortening of moving rods (length contraction), the student treated them as being actually distortions of perception.

Hewson (1982) interpreted these findings as being the result of the individual assimilating the two propositions into his prior metaphysical world view, one which was mechanistic. This was accomplished through using the perception argument to overcome the direct contradiction between the old and new concepts. The author then had considerable success in changing the individual's metaphysical commitment using an intervention based on the conceptual change model. This involved helping the student to lower the status of his Newtonian conception, breaking down the reconciliation between the Newtonian and STR conceptions and elevating the status of the STR conception, effectively causing a conceptual exchange (accommodation).

The preliminary success of the model in addressing learning difficulties through the use of instructional materials based on it has been demonstrated with the concepts of special relativity (Posner et al., 1982), mass, volume, and density (M. Hewson, 1981; Hewson and Hewson, 1981), speed (Hewson, 1983), and velocity (Zietsman and Hewson, 1986). It will therefore be used in this study as
a set of theoretical constructs to interpret change (or no change) in students' conceptions held before and after instruction in growth and the cell.

This research can be seen as being located within the constructivist tradition in educational psychology. Its contribution to theory is centered on providing evidence for the importance of prior knowledge to learning in biology and contributing to the usefulness of the Posner et al., (1982) model of conceptual change as an explanatory and predictive construct in science education.

2.4 The Educational Context of the Study

2.4.1 Curriculum

Fensham (1983) has suggested that the objectives of the majority of science curricula used in schools fall into five broad categories of concern:

1. Concerns for the factual and theoretical (conceptual) knowledge of science.

2. Concerns for the process of scientific investigation and reasoning.

3. Concerns for practical (laboratory) investigations in science.

4. Concerns for attitudes towards science and attitudes associated with science.

5. Concerns for the relation of science to society. (Fensham, 1983, p. 5)

He argues that these objectives reflect the following instructional sequence of process as viewed by curriculum
developers:

(Learner) + Appropriate Instructional Input -> Intended Learning Outcomes of Science Education

This view puts the predominant emphasis in curriculum development on definition of learning outcomes and developing materials which are designed to meet these outcomes. Learners have characteristically been considered (if at all) as blank slates as far as this process is concerned (Fensham, 1983).

Deadman and Kelly (1978) make much the same claim except that they would likely place the "Appropriate Instructional Input" before the "(Learner)" in the diagram above. They suggest that curriculum development has followed what they refer to as the "curriculum-to-pupil" mode where the materials and strategies are first developed and then tried out on students. Based on specified criteria of success, they are then either rejected, accepted or revised.

The research discussed earlier in this chapter related to students' prior knowledge strongly suggests that there must be a shift in emphasis in curriculum development away from learning outcomes and toward the learner. Deadman and Kelly in 1978 referred to this new emphasis as a pupil-to-curriculum mode in development, whereby:

...pupils' understanding of a topic is investigated first and then, through a...process in which development, research, and teaching are combined, ways are explored
directly with pupils by which their understanding can be increased. (Deadman and Kelly, 1978, p.8)

Some measure of the prevalence of the pupil-to-curriculum orientation in curriculum can be obtained from examining a study by Roberts (1982). He analysed the curriculum emphases advocated in policy statements and textbooks in science education practise "over the last eighty years or so" and identified seven major threads: Everyday Coping; Structure of Science; Science, Technology, and Decisions; Scientific Skill Development; Correct Explanation; Self as Explainer; and Solid Foundation. Only one of these emphases, Self as Explainer, has a reference to according some sort of status to individuals' idiosyncratic set of explanations. Even within this emphasis, however, the students are informed that they make sense only insofar as they are trying to explain their view of the phenomena.

In recommending future progress, Roberts (1982) suggests that all these emphases should be stressed, rather than using the present model where one emphasis replaces another because it is considered more innovative or modern. No suggestion is made, however, to including a "Student as Knower" emphasis.

A major four year study of Canadian science education conducted by the Science Council of Canada (1984) included as one its of three primary aims "to stimulate active deliberation concerning future options for science education
in Canada" (Orpwood, 1985). Within the framework of "deliberative inquiry" (Orpwood, 1985), a vast array of data analysis methodologies were brought to bear across Canada in order to determine the present status of science education in the country. This data was then considered in a series of two-day invitational conferences in each of the 11 provinces and territories in Canada in which members from a wide range of professions and occupations both within and outside of the educational establishment debated future needs.

The Science Council of Canada (1984) summarized these needs in the form of eight recommendations:

1. Guaranteeing science education in every elementary school.
2. Increasing participation of young women in science education.
3. Challenging high achievers and science enthusiasts.
4. Presenting a more authentic view of science.
5. Emphasizing the science-technology-society connection.
7. Introducing technology education.
8. Ensuring quality in science education.

In this list of recommendations there is no reference, either explicitly or implicitly, to addressing students' learning difficulties in science education, much less stressing a student-to-curriculum emphasis in the development of curricula. Rather, the alternative mode is
clearly stressed under recommendation (8):

Assessment techniques must be developed and implemented for all the objectives of science education to inform individual students about their progress and to monitor the effectiveness of provincial science education systems. (Canada Science Council, 1984, p. 43)

The new curriculum and assessment framework proposed for the British Columbia school system presented in the draft document entitled *Year 2000: A Curriculum and Assessment Framework for the Future* (British Columbia Ministry of Education, 1989) reflects a change in emphasis toward the learner. The principles regarding learning and the learner on which the new framework is based include the view that "the learning process involves individuals selecting from available information, and constructing meaning by placing the new information in the context of what the individual already knows, values, and can do (British Columbia Ministry of Education, 1989, p. 9)". Furthermore:

How each individual learns about a particular concept or conceptual relationship is a function not only of chronological age, but also of personal interests, learning style preferences, abilities, the learning opportunities and experiences which that individual had in the past, and the characteristics of the learning environment. (p. 10)

How these principles will be applied in the actual curriculum development process is not yet clear at this time.

The extent to which the growing implications of the
alternative conceptions movement have a practical effect on instruction and curriculum development depends in a large part on how effectively these implications are communicated outside of the research community.

2.4.2 The Classroom

The instructional setting is one of the most basic and important elements in considering individuals' conceptions and how they interact with new conceptions. It is in the classroom that students' knowledge is constantly confronted with new interpretations of phenomena and forced, through the prospect of evaluation, to in some way come to grips with these interpretations. In the classroom also lies the greatest, if not only, opportunity for elucidating students alternative conceptions and implementing strategies to help them assimilate or accommodate new conceptions.

Gilbert, Osborne, and Fensham (1982) have identified an important element which is often overlooked in considering the interaction between what they refer to as children's science (views of the natural world before formal science teaching) and scientists' science (consensual scientific view of the world). This element they refer to as teachers' science, which represents the teacher's view of science. It is these conceptions which the children actually confront in the classroom and which are based on the following
interaction (Gilbert et al., 1982, p. 628):

| Science Curricula + Teachers and Materials | Lesson Science Prep | Modified Science Science |

Teachers are equally knowing beings who construct knowledge on the basis of experience (including schooling) and may have alternative conceptions of scientific phenomena. Since it is the teachers' conceptions which students actually confront, one can not immediately assume that a student's alternative conception after instruction is a result of incomplete accommodation of scientists' science, for example. The student may have completely accommodated a teacher's alternative conception.

Within the framework of the classroom, Gilbert et al. (1982) have identified five possible outcomes of the interaction of children's science and teachers' science:

1. The undisturbed children's science outcome.
2. The two perspectives outcome.
3. The reinforced (children's science) outcome.
4. The mixed outcome.
5. The unified science outcome.

These outcomes can all be related to Posner's et al. (1982) theory of conceptual change. The first might be a result of the rejection by the child of the teacher's conception, the second the result of rote memorization, the third and fourth a result of assimilation and the fifth a result of either successful assimilation or accommodation.
This "outcomes" perspective will be a valuable guide in interpreting the results of this study.

More directly, this study will provide teachers with a list of students' conceptions regarding both the concepts of growth and the cell. The results from this limited sample may serve as a preliminary guide to those alternative conceptions that may be most fruitfully pursued by the teacher in the limited time she has available in the instructional environment. Furthermore, the study will provide teachers with information regarding change in students' conceptions after instruction which is based on individual interviews which a teacher seldomly has the opportunity to carry out. This research provides individual teachers with a source of data, other than their own evaluations, on which they can base decisions regarding the teaching of growth and the cell in their classrooms.
CHAPTER THREE

METHODS OF THE STUDY

3.0 Introduction

This chapter presents a discussion of the methods and procedures used in this study. The methods employed in identifying the characteristics of the concepts of growth and the cell used in the development of the interview protocols are discussed as are the tasks and protocols themselves. The methods of data collection are addressed, including general considerations of the clinical interview methodology and the specific procedures proposed for this study. The sample of students is described. The procedures and issues related to data analysis are discussed in Chapter 4.

3.1 Concept Characteristics of Growth and the Cell

In order to investigate students' conceptions of growth and the cell it was first necessary to analyse these phenomena and identify the characteristics or meaning
central to them from the scientific perspective. The aim of this analysis was to obtain propositional representations of the concepts on the basis of which interview protocols could be constructed.

The method of analysis described below is a modification of that used by Stewart and van Kirk (1981) in developing a model of conceptual knowledge in genetics. Hackling and Treagust (1982) also used a modification of this method in identifying a sequence of propositions which would lead to an understanding of inheritance. As in this study, the list of propositions was used as the basis for the development of an interview protocol.

Relevant chapters in texts, curricular materials and guides were analysed and converted into propositions related to growth and the cell. Relationships between propositions were then identified and added to the lists. The items in the lists were then grouped under a number of general headings.


The list of characteristics for the concept of growth was submitted to two elementary teachers and one biologist for comment. The list was then revised, discussed and agreed upon. This final representation of the concept of growth will henceforth be referred to as the Growth Characteristics List or GCL and is presented in Table 1. In terms of generality, its use is appropriate to the high school level.

The majority of characteristics identified in the GCL were also identified, although at a less specific level, in a representation of the concept of growth constructed from free associations made by high school biology teachers (Schaefer, 1979).

The list of characteristics for the concept of cell was submitted to two secondary science teachers and one biologist for comment. This list was then also revised, discussed and agreed upon. This final representation of the concept of the cell will henceforth be referred to as the
Cell Characteristics List or CCL and is presented in Table 2. Pella (1966) identified, and subsequently investigated (Pella and Strauss, 1969; Billeh and Pella, 1970), 11 sub-concepts on the basis of textbook analyses which he considered necessary for an understanding of the biological cell. These 11 sub-concepts were also identified in this study and are included in the CCL.

TABLE 1

The characteristics of growth

1. PARAMETERS OF GROWTH

G1. Growth is a property of living things.

G2. Growth is the development of different parts of an organism.

G3. Growth is the increase in size of the parts of an organism.

G4. Living things are made up of small units called cells.

G5. The division of cells into different cells results in the development of the different parts of organisms.

G6. The division of cells into identical cells results in the increase in size of the parts of organisms and thus the organisms themselves.

G7. Growth involves the increase in size, to a limit, of cells.

2. SOURCES AND ACQUISITION OF REQUIREMENTS FOR GROWTH

G8. Plants need carbon dioxide and oxygen.

G9. Plants need water.


G11. Plants need minerals from the soil. Sixteen elements in these minerals make up plants' nutritional requirements.
TABLE 1 (continued)

The characteristics of growth

G12. Animals need three major food molecules, carbohydrates, proteins and fats. They also need amino acids, vitamins and minerals.

G13. Animals need water.


G15. Plants obtain carbon dioxide and oxygen from the air.

G16. Plants obtain water from the soil.

G17. Plants obtain light from the sun or artificial lights.

G18. Plants obtain minerals from the soil.

G19. Animals obtain water, food molecules, amino acids, vitamins, and minerals from a variety of sources.

G20. Animals obtain oxygen from the air.

G21. Water is taken into the plant from the soil via the roots and then moves to the leaves.

G22. Light is taken into the plant and used directly by special cells in the leaves.

G23. Carbon dioxide is taken into the plant by the leaves and is used by special cells in the leaves.

G24. Minerals are taken into the plant from the soil via the roots and are moved to all parts of the plant.

G25. Animals take in the three major food molecules, amino acids, vitamins and minerals, in the form of foodstuffs, through the mouth.

G26. Animals take in water through the mouth.

G27. Animals take in oxygen through the mouth and nose. It then goes to the lungs.

3. USE OF REQUIREMENTS FOR GROWTH BY THE ORGANISM

G28. Carbon dioxide, water, and light are all used by special cells in the leaves of a plant to make food for the plant.
TABLE 1 (continued)

The characteristics of growth

G29. This food is transported from the leaves to other parts of the plant.

G30. The cells of parts of plants use this food and minerals, in part, to make new cells.

G31. Only some of the water taken in by plants is used in the production of food, most is lost to the air.

G32. Oxygen is given off by the leaves as waste.

G33. When there is no light, the making of food in plants stops.

G34. Food stuff in animals is ground up by the stomach and then the major food molecules are absorbed by the small intestine and passed to the blood.

G35. Water is absorbed by the large intestine and passed to the blood.

G36. Oxygen is absorbed by the lungs and passed to the blood.

G37. Organs in the body convert the major food molecules into sugar, which goes to all cells via the blood and, fats, which are stored.

G38. Cells in the body use sugar and oxygen, in part, to make new cells.

G39. Wastes from the cells (carbon dioxide) and excess water are passed into the blood and excreted.

G40. Waste from the body is excreted.

G41. Nutrition and other factors can affect the rate of growth in animals and plants.

4. INSTIGATION OF GROWTH

G42. A plant develops from a seed.

G43. Seeds are a result of the combining of the pollen and egg of plants.

G44. Seeds are alive but not growing (dormant) because the seed coat keeps out water and gases.
**TABLE 1 (continued)**

**The characteristics of growth**

<table>
<thead>
<tr>
<th>G45.</th>
<th>Seeds contain the embryo of a plant, which is only a shoot and a root.</th>
</tr>
</thead>
<tbody>
<tr>
<td>G46.</td>
<td>Seeds start growing for a number of reasons depending on the type of plant, these include wearing down of the seed coat or the breaking down of inhibitors in the coat due to heat, cold or light.</td>
</tr>
<tr>
<td>G47.</td>
<td>Dormancy ends with a massive entry of water into the seed. The emerging embryo then ruptures the seed coat completely and the plant begins to grow.</td>
</tr>
<tr>
<td>G48.</td>
<td>Animals are created by the union of an egg from a female and a sperm from the male.</td>
</tr>
</tbody>
</table>

**5. CESSATION OF GROWTH**

<table>
<thead>
<tr>
<th>G49.</th>
<th>Organisms have a range of tolerance for different elements in their environment and can only survive within those limits.</th>
</tr>
</thead>
<tbody>
<tr>
<td>G50.</td>
<td>An organism dies when certain of its cells die which cannot be replaced.</td>
</tr>
<tr>
<td>G51.</td>
<td>Plants continue to grow throughout their entire lifetime.</td>
</tr>
<tr>
<td>G52.</td>
<td>Plants die when they stop growing. Plants die for a variety of possible reasons: they flower, it may be genetically programmed, or at a point when so many non-photosynthetic cells exist in the plant that the food producing cells cannot make enough to feed the plant.</td>
</tr>
<tr>
<td>G53.</td>
<td>Animals stop growing at a certain time. At this time cells do not develop into different cells, and the production of new cells by division balances the death of old cells.</td>
</tr>
<tr>
<td>G54.</td>
<td>Most animals stop growing at a certain time (cell increase) and may experience a period of negative growth (cell decrease) in old age.</td>
</tr>
<tr>
<td>G55.</td>
<td>Most animals age, or progressively deteriorate in terms of structures and function, with the passage of time.</td>
</tr>
</tbody>
</table>
TABLE 1 (continued)

The characteristics of growth

G56. Aging may be the result of environmental effects, genetic coding, the wearing out of function and structure as a result of use or the buildup of deleterious chemicals in the system.

G57. Death can result from the gross suspension of function, disease or aging.

G58. Death results also from the lack of requirements, including oxygen, food or water.

TABLE 2

The characteristics of the cell

1. STRUCTURE OF ORGANISMS

C1. All living things are made up of cells. Only living things contain cells.

C2. Some organisms are made up of only one cell.

C3. Most organisms are made up of many cells.

C4. Organisms differ in size depending on the number of cells they possess, not on the size of individual cells.

C5. Organisms differ in the way they look because of differences in the number and kinds of cells they possess and the way these cells are organised.

C6. Cells are connected, this holds organisms together.

C7. Actions of organisms are a result of cells sending messages directly from one cell to another and by their producing chemicals which flow through the organism to other cells.

C8. More than 100 trillion ($10^{14}$) cells make up a human adult.

2. METABOLISM OF ORGANISMS

C9. Organisms obtain a variety of requirements for life and growth from the environment.
TABLE 2 (continued)
The characteristics of the cell

C10. Carbon dioxide, water, and light are used by special cells to make food for the plant.

C11. Animals take in food and oxygen which are passed into the bloodstream and are then reacted by cells in the body.

3. GROWTH OF ORGANISMS

C12. Single celled organisms make new organisms by making a copy of their DNA and splitting in half. This results in two identical new organisms each with a copy of the original DNA.

C13. Multicellular organisms produce a single-celled zygote when an egg cell from a female is fertilized by a sperm cell from a male. This zygote has DNA in the form of chromosomes from both the male and female.

C14. A multicellular adult organism develops from a single-celled zygote by repeated cell division hence all body cells of a given offspring have the same DNA.

C15. The process of cell division is made up of mitosis; the division of the chromosomes, and cytokinesis; the division of the cytoplasm, and occurs through a number of observable physical changes in the cell.

C16. The zygote initially divides about every 10 hours, turning into 2, 4, 8, 16, 32, etc., cells.

C17. Up to the 32 cell stage all the cells are identical in structure, after that cells begin to differentiate, that is the cells begin to differ in function and structure (i.e., those leading to bone, skin, muscle, nerve, blood, etc.)

C18. The DNA in the original cell carries the instructions to make the different kinds of cells.

C19. These differentiating cells are the origins of the different organs we see in organisms.

C20. Some cells have little (eg. muscle cells) or no (eg. brain cells) ability to divide after the first few months after birth.
TABLE 2 (continued)
The characteristics of the cell

C21. Some cells (blood cells, skin cells, cells lining the organs) divide constantly.

C22. The rate of division of cells is controlled in order to keep the number about the same. About 1.5 million red blood cells are produced every second, they last about 127 days. About 1.5 million blood cells also die every second. This is repair.

C23. Some cells divide faster than they die resulting in growth of organisms.

C24. Cancer cells are normal cells which no longer have their rate of division controlled.

C25. Environmental factors influence the development of offspring and control the extent to which the genetic potential of the individual is achieved.

4. THE STRUCTURE OF CELLS

C26. Most cells are too small to see with the human eye.

C27. Cells have a basic structure.

C28. All cells are surrounded by a thin, flexible membrane.

C29. All cells have cytoplasm contained by this membrane.

C30. Virtually all cells have a nucleus surrounded by the cytoplasm.

C31. All cells have chromosomes made up of DNA which are in the nucleus.

C32. The cell wall of plants is made of non-living material (cellulose) secreted by cells.

C33. Cells have a complex internal organization with many specialized structures.

C34. Plant cells differ in structure depending on their function.

C35. Animal cells differ in structure depending on their function.

C36. Cells cannot grow to an indefinite size.
TABLE 2 (continued)

The characteristics of the cell

C37. Cells contain mainly water.

C38. Most of the structures in cells are made of protein molecules. Cells also contain fat molecules.

5. METABOLISM OF CELLS

C39. The activities associated with life are carried on in the cell.

C40. Cells break food molecules into smaller molecules.

C41. Cells carry out metabolic processes which react fragments of food molecules with oxygen.

C42. These metabolic processes release energy.

C43. These metabolic processes result in the building of large fat molecules which store chemical energy.

C44. These metabolic processes build large protein molecules which are used to build new cells (growth), and repair old cells.

C45. DNA is an important molecule concerned with the regulation of cell activities.

C46. DNA replicates itself and also serves as a template for RNA formation involved in the regulation of cell activities.

C47. When cells run out of food and oxygen they die.

3.2 The Interview Protocols

3.2.1 Introduction

In selecting a data collection methodology for this study, two factors were of primary importance. First, the methodology had to allow for the in depth probing of students' ideas with respect to the two concepts, what
Erickson (1979) refers to as the "substance" of their actual beliefs. This requirement involves both providing students with the greatest flexibility in expanding on their ideas and allowing the investigator to pursue pertinent and revealing remarks. Secondly, since this study is concerned not only with identifying students' conceptions but also investigating how they change, the methodology also has to allow comparisons to be made between conceptions as they are expressed by students at different times. The method which most fully meets these two requirements is the semi-structured clinical interview.

Jean Piaget (1969) was the first to take the interview, a psychoanalytic method aimed at diagnosis, and develop it into a data acquisition technique for research - his "clinical method". Its primary use in educational research has been to "ascertain the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and perceived relationships among these conceptions" (Posner and Gertzog, 1982). The method's facility at achieving this end over a wide range of content areas and age groups has lead to its increased popularity in science education and its widespread acceptance as a data collecting methodology (See Posner et al., 1982; Driver and Easley, 1978; Donaldson, 1978; Posner and Gertzog, 1982; Pines and Novak, 1985).
The structure of the interview as it has been used in research studies has characteristically ranged along a continuum of unstructured to structured depending on the objectives of the research. In meeting the requirements addressed above, the structure selected for this study rests at the midpoint on this continuum. It consists of a number of standardized questions and "tasks" that are relevant to the topics in question yet that are not so fixed as to restrict the interview to a structured and inflexible question-answer format. Provision is thus made for comparison while also allowing students the freedom to expand on their responses and the investigator the ability to pursue those responses.

3.2.2 Development of the Interview Protocols

The List of Growth Characteristics was used as a guide in developing a set of questions and tasks to be used in identifying students' conceptions of growth. Each of the questions was developed in such a way as to address one or more of the characteristics on the LGC while at the same time not leading the student to those particular characteristics. For example, the question, "What does a tree need to grow?" addresses Growth Characteristics 8-11 (See LGC, p. 55) while not biasing the student toward those requirements. The question also allows for the student's own conceptions which may be different from the scientific conceptions represented by the LGC. A number of the
characteristics are addressed in more than one question, allowing a check on the level of a student's commitment to his ideas.

The questions were oriented around two contexts, plants and humans. This was done for a number of reasons: students might be expected to have experience with growth in both; they receive instruction in plant growth and not human growth, thus allowing for later comparison; and some elements of growth in plants and humans are the same, also allowing for later comparison.

The completed growth interview was pilot tested with three grade 3 students (ages 8 years 3 months, 8.7, 9.1) prior to their first exposure to formal instruction in growth and plants. The students were asked specifically to comment on questions or objects used in the interview that were confusing or unclear. The audio-tapes of the interviews and the students' comments were used to modify the protocol. This revised interview protocol, referred to as the Growth Protocol, was used in this study and is presented in Section 3.2.3 below.

The development of the Cell Protocol, using the List of Cell Characteristics as a guide, was similar to that the Growth Protocol with the following differences. The first nine questions chosen for the cell interview are also included in the growth interview. This allows for the identification of students' conceptions regarding growth at
the higher age level (15-16), at which this protocol was used, while at the same time providing essential information on whether the student links the macroscopic concept of growth with the microscopic concept of cell. The nine questions thus address both characteristics of growth included in the LGC and the more specific characteristics included in the LCC.

The questions and tasks were piloted with 1 grade 10 student (age 15.1) prior to her receiving instruction in the cell and two grade 10 students (ages 15.6, 15.8) after they received instruction in the cell. The students were asked specifically for comments regarding questions or objects used in the interview that were unclear or confusing. The interview protocol was modified on the basis of audio-tapes of the interviews and the students' comments. The Cell Protocol is presented in Section 3.2.4 below.

3.2.3 The Growth Interview Protocol

Each subject was interviewed alone in a quiet room in the school. The subject was told that the results of the interview would not be made known to peers, teachers, or parents and that the interview was being audiotaped. The subject was told that the investigator was interested in some of his or her ideas about plants and animals. The format of the interview consisted of presenting the subject with a drawing or an object and then posing a series of
questions related to the drawing and/or object. Attempts were then made to have the subject expand and explain his or her answers by initiating open-ended discussion. Each interview lasted approximately 40 minutes.

Materials

1. A drawing of five rocks, all the same shape and general appearance, progressing in size from small to large. The drawing was executed by hand on hard paper stock (71cm X 40cm).

2. A drawing of a tree, progressing through five stages from a seed to an adult tree. The drawing was executed by hand on hard paper stock (71cm X 40cm).

3. A drawing of a dog, progressing through five stages from a puppy to an adult dog. The drawing was executed by hand on hard paper stock (71cm X 40cm).

4. A drawing of a human male, progressing through five stages from an infant to an adult. The drawing was executed by hand on hard paper stock (71cm X 40cm).

5. A Douglas Fir sapling (approximately 14cm in height) planted in soil in a pot.

The Growth Interview

The subject was presented with the four drawings described above and was then asked the following question:

GQ1. Look at the four drawings, what do you think is happening in them?

(Addresses Growth Characteristics 1-3, Table 1).

If the subject identified the rock as growing or the tree, dog or human as not growing, the drawing(s) were singled out and the question posed again:

GQ2. Look at this drawing, what do you think is happening here?
Those drawings identified by the subject as not illustrating growth were then removed and the following question was asked with reference to the remaining drawings:

GQ3. How can you tell that the things in the drawings are growing?

(Growth Characteristics 2, 3, Table 1).

The drawing of the tree was then singled out and placed before the subject as was the Douglas Fir sapling. The following questions were then posed with reference to both the drawing and the sapling:

GQ4. What does a tree need in order to grow?
   (Growth Characteristics 8-11, Table 1).

GQ5. How do the things a tree needs to grow get inside it?
   (Growth Characteristics 15-18, 21-24, Table 1).

GQ6. When the things a tree needs get inside the tree, do they look the same as when they did outside?
   (Growth Characteristic 4, Table 1).

GQ7. Once the things a tree needs are inside, how are they used to make the tree grow?
   (Growth Characteristics 5-7, 28-33, Table 1).

GQ8. What can cause a tree to grow poorly?
   (Growth Characteristics 49, 50, 57, 58, Table 1).

GQ9. What makes a tree start growing?
   (Growth Characteristics 42-47, Table 1).

GQ10. Do all trees grow to be the same size?
(Growth Characteristic 41, Table 1).

GQ11. Do trees ever stop growing?

(Growth Characteristics 51, 52, Table 1).

The drawing of the tree and the Douglas Fir sapling were then removed and the drawing of the human singled out and placed before the subject. The following questions were then posed with reference to both the drawing and the subject him/herself:

GQ12. What does a person need in order to grow?

(Growth Characteristics 12-14, Table 1).

GQ13. How do the things a person needs to grow get inside him or her?

(Growth Characteristics 19, 20, 25-27, Table 1).

GQ14. When the things a person needs get inside the person, do they look the same as when they did outside?

(Growth Characteristic 4, Table 1).

GQ15. Once the things a person needs are inside, how are they used to make the person grow?

(Growth Characteristics 5-7, 34-40, Table 1).

GQ16. What can cause a person to grow poorly?

(Growth Characteristics 49, 50, 57, 58, Table 1).

GQ17. What makes a person start growing?

(Growth Characteristic 48, Table 1).

GQ18. Do all people grow to be the same size?

(Growth Characteristic 41, Table 1).
GQ19. Do people ever stop growing?
   (Growth Characteristics 53-56, Table 1).

GQ20. Do you remember ever growing plants in the classroom or at home, raising a pet, or having a baby brother or sister?
   (This question was included in order to probe the individual's past experience with growth as a biological phenomena).

The subject was then asked for his or her birthdate and whether he or she had any questions to ask the interviewer. This concluded the Growth Interview.

3.2.4 The Cell Interview Protocol

Each subject was interviewed alone in a quiet room in the school. The subject was told that the results of the interview would not be made known to peers, teachers, or parents and that the interview was being audiotaped. The subject was told that the investigator was interested in some of his or her ideas about plants and animals. The format of the interview consisted of presenting the subject with a drawing, a photograph or an object and then posing a series of questions regarding the item(s). Attempts were then made to have the subject expand and explain his or her answers by initiating open-ended discussion. Each interview lasted approximately 35 minutes.

Materials
1. A drawing of a tree, progressing through five stages
from a seed to an adult tree. The drawing was executed by hand on hard paper stock (71cm X 40cm).

2. A drawing of a human male, progressing through five stages from an infant to an adult. The drawing was executed by hand on hard paper stock (71cm X 40cm).

3. A fixed and stained cross-section of an onion root tip on a microscope slide. The specimen was observed through a Wild light microscope at a magnification of 400X. A pointer in the eyepiece of the microscope was directed at an onion cell in the interphase stage of mitosis.

4. A photomicrograph (16cm X 18cm) of a fixed and stained cross-section of an onion root tip enlarged 1500X. Letters on the photomicrograph indicated the following:
   a. a cell in the interphase stage of mitosis,
   c. a cell in the prophase stage of mitosis,
   b. a cell in the metaphase stage of mitosis,
   e. a cell in the anaphase stage of mitosis,
   d. a cell in the telophase stage of mitosis,
   f. the nucleus of a cell,
   g. the chromosomes of a cell,
   h. the cytoplasm of a cell.

The Cell Interview

The subject was presented with the two drawings described above and was then asked the following question:

CQ1. Look at the two drawings, what do you think is happening in them?
   (Addresses Cell Characteristics 1, 14, 17, 23, Table 2).

The drawing of the tree was then singled out and placed before the subject. The following questions were then posed with reference to the drawing:

CQ2. What does a tree need to grow?
   (Cell Characteristics 9, 25, Table 2).

CQ3. What goes on inside the tree which results in its
growth?

(Cell Characteristics 10, 14, 23, 40-42, 44, Table 2).

CQ4. What makes a tree start growing?

(Cell Characteristics 12, 13, Table 2).

CQ5. Does a tree ever stop growing?

(Cell Characteristics 20-23, Table 2).

The drawing of the tree was then removed and the drawing of
the human placed before the subject. The following questions
were then posed with reference to the drawing:

CQ6. What does a person need to grow?

(Cell Characteristics 9, 25, Table 2).

CQ7. What goes on inside a person which results in its
growth?

(Cell Characteristics 11, 14, 23, 40-42, 44, Table 2).

CQ8. What makes a person start growing?

(Cell Characteristic 13, Table 2).

CQ9. Does a person ever stop growing?

(Cell Characteristics 20-23, Table 2).

CQ10. Where do the different parts of an organism come from?

(Cell Characteristics 14, 17, 19, Table 2).

The drawing of the tree was then placed before the
subject. The subject was then asked to examine the object
under the microscope. The following questions were then
posed with reference to the object and the drawing:

CQ11. What do you think the object is that the pointer is
indicating?
CQ12. Does the object have anything to do with the tree in the drawing?

CQ13. Does the object or ones like it have anything to do with the beginnings of organisms?

CQ14. Does the object or ones like it have anything to do with the origins of different parts of organisms?

CQ14a. Does the object or ones like it have anything to do with how an organism works?

The drawing of the tree and the photomicrograph were then placed before the subject and the following questions were posed with reference to the drawing and the photomicrograph:

CQ15. Do you think there is any relationship between anything in the photograph and what is happening in the drawing?

CQ16. How does a cell work?

CQ17. Where do cells come from?

CQ18. What controls how a cell works?
CQ19. What causes an organism to die?
   (Cell Characteristics 24, 47, Table 2).
CQ20. What is your understanding of the terms mitosis and meiosis?
   (Question CQ20 was included in order to examine students' understanding of these two processes).
CQ21. Do you remember ever having studied growth or the cell in the classroom?
CQ22. Do you remember ever growing plants in the classroom or at home, raising a pet, or having a baby brother or sister?
   (Questions CQ20 and CQ21 were included to probe the individual's past experience with growth and the cell as biological phenomenon).

The subject was then asked for his or her birthdate and whether he or she had any questions to ask the interviewer. This concluded the Cell Protocol.

3.3 Considerations of Validity and Reliability

The validity and reliability of the methodology for data collection and analysis employed in a study is of concern in all forms of research. In terms of validity, the methodology should employ instruments that represent those concepts they are designed to assess. The interview protocol development process used in this study was an effort to maximize this form of validity. The development of Lists of
Characteristics for both concepts with the cooperation of a biologist and teachers and the development of interview questions based directly on these lists were efforts to ensure that the instrument accurately represented the concepts in question. By discussing the interview protocol with students in all target age groups and analysing the transcripts in the pilot study, the protocols were modified to remove any sources of confusion which the structure of the interview might present to students.

The consistency with which a subject answers questions repeated within an interview can be used as an indicator of how well the interview elicits conceptions held by the subject regarding the concept as opposed to responses made spontaneously by the subject in order to satisfy the interviewer. In the 6 pilot interviews conducted prior to this study, a number of the questions were repeated during the course of each interview. In some cases the context was slightly changed, but not to the extent that it could be expected to alter the response. For example, a student was asked the requirements for growth of a fir tree early in the interview and then later asked the requirements for growth in a pine tree. Of a total of 46 questions asked twice in this manner, only 2 were found to elicit different responses.

Efforts to ensure the reliability of the methodology included the use of a semi-structured interview protocols
and the tape recording of all the interviews. Reliability with respect to the assessment of the interview data will be discussed in Chapter 4.

3.4 The Sample of the Study

As discussed in Chapter One, this study was conducted in two phases. The first phase addressed Research Questions 1 and 3, related to the growth concept at the elementary school level, while phase two addressed questions 1, 2, and 4, related to the growth and cell concepts at the junior secondary school level. Phase one of the study consisted of two parts. The first part was directed at determining students' conceptions of growth at the grade 3, 5, and 7 level.

Eleven students, aged 8 years, 6 months to 10 years 2 months (grade 3) were interviewed using the Growth Protocol one week prior to their participation in a three week instructional unit on the forest community. The unit was based on the grade 3 textbook *Space-Time-Energy-Matter* and was entitled "Communities and Living Things". The teacher supplemented the text activities with her own materials which were related predominantly to growth in plants.

The children were from an elementary school in the City of Vancouver, British Columbia and were selected by the teacher as representing a mixture of socio-economic and
ethnic backgrounds and a range of achievement in school. Prior to the unit, none of the sample children had received instruction with respect to growth. This was confirmed with the children and their previous teachers. The sample included four girls and seven boys.

A further 10 students in grade 5 (ages 10.3-12.2) and 10 students in grade 7 (ages 12.2-14.4) were interviewed using the Growth Protocol. The grade 5 sample was made up of 5 females and 5 males. The grade 7 sample included 6 females and 4 males. The students were from a different elementary school in Vancouver than the one which supplied the grade 3 sample discussed above. The students were selected by their teachers as representing a mixture of socio-economic and ethnic backgrounds and a range of achievement in school. The students' histories with respect to instruction in the growth concept were investigated by consulting members of the staff and by analysing student responses to Growth Protocol Question 20. Teachers reported that it is was almost certain that the students would have encountered at least one unit dealing with the concept in their schooling prior to grade 5.

The second part of phase one dealt with Research Question 3, that is, investigating the nature of change in student conceptions of growth at the grade 3 level after first instruction in the concept.

The grade 3 students discussed above were interviewed
three weeks after completing the "Communities and Living Things" unit using the Growth Protocol. Eight of these original 11 subjects were available to be interviewed two years later, again using the Growth Protocol.

The second phase of the study was aimed at investigating students conceptions of growth and the cell at the grade 10 level (Research Questions 1 and 2) and the nature of the change in these conceptions after receiving instruction on the cell (Research Question 4). For this phase, 5 students from each of 4 secondary schools, 2 urban, and 2 sub-urban, were interviewed using the Cell Protocol. All of the schools were located in the Greater Vancouver area of B.C. The students' ages ranged from 15.5 to 17.0. Ten of the students were males and 10 were females.

The students were selected by their teachers as representing a mixture of socio-economic and ethnic backgrounds and a range of achievement in school. The students had not participated in formal instruction in the cell at the secondary level prior to the interview. This was confirmed by consulting members of the staff and the students themselves. Ten students reported that they had heard of the cell in elementary school.

After the first interview, the students participated in the Science Probe 10 (Wiley, 1984) unit "The Basic Unit of Life: The Cell". This unit is prescribed in the British Columbia grade 10 science curriculum. Four weeks after
having completed the unit, the students were again interviewed using the Cell Protocol.

In total, 51 different students from grades 3, 5, 7, and 10 were interviewed, providing the data for this study. As discussed above, efforts were made to secure a sample of students representing an equal distribution of males and females, and a range of abilities and backgrounds. It is not thereby implied, however, that the selection criteria were rigorous enough to allow specific statistical inferences to be made regarding conceptions held by the general population of students based on this sample. This study was exploratory and descriptive in nature and as such was designed to identify those conceptions or areas of learning difficulties that can most fruitfully be investigated by the range of experimental and observational methodologies currently available to the researcher. Specific recommendations are discussed in Chapter Six.
CHAPTER FOUR

STUDENTS' CONCEPTIONS OF GROWTH AND THE CELL

4.0 Introduction

This chapter presents the results relating to the first two research questions posed in this study, namely:
1. What are students' conceptions of growth in plants and animals in grades 3, 5, 7, and 10?
2. What are students' conceptions of the cell in grade 10?
The results relating to changes in the students' conceptions (Research Questions 3 and 4) are discussed in Chapter 5.

This chapter is divided into four major sections, apart from this introduction. The first section discusses the methods of data analysis. It provides examples of the methods and includes considerations of reliability. The results related to the concept of growth are presented and discussed in section 2, those related to the cell in section 3. The chapter closes with a general discussion of the results and how they relate to the two research questions.
4.1 Data Analysis

4.1.1 The Compilation of Individual Conceptual Inventories from Interview Transcripts

The method selected to analyse the data is a modification of Conceptual Propositional Analysis (CPA) (Pines, 1977; Pines and Novak, 1985). A transcript of each interview was prepared. The statements made by each student in response to the questions posed in the protocols were identified on the transcript and in some cases longer statements were broken into shorter statements. These statements were then referred to as conceptions and were taken as evidence of the student's underlying beliefs concerning the relevant question. "I do not know" responses were also identified.

For each student the conceptions were then organized under the broad general headings used in the Growth and Cell Characteristics Lists. These general headings were slightly modified in order to better represent the conceptual areas under consideration. The general headings, or constituent concepts, and the protocol questions associated with them are presented in Table 3. The organized collection of all of a student's conceptions was referred to as an individual "conceptual inventory" (Erickson, 1979). It offers an overall perspective of each individual's conceptions and represents the first level of data reduction used in this study.
TABLE 3

The constituent concepts for growth and the cell and their associated Protocol questions (GQ = Growth Protocol question, CQ = Cell Protocol question)

1. The parameters of growth
   a. Plant and Animal
      
      GQ1. Look at the four drawings, what do you think is happening in them?
      GQ2. Look at this drawing, what do you think is happening here?
      GQ3. How can you tell the things in the drawings are growing?
      CQ1. Look at the two drawings, what do you think is happening in them?

2. Sources and acquisition of requirements for growth
   a. Plant
      
      GQ4. What does a tree need in order to grow?
      GQ5. How do the things a tree needs get inside?
      CQ2. What does a tree need to grow?
   b. Animal
      
      GQ12. What does a person need in order to grow?
      GQ13. How do the things a person needs to grow get inside him or her?
      CQ6. What does a person need to grow?

3. Use of requirements for growth by the organism
   a. Plant
      
      GQ6. When the things a tree needs get inside the tree, do they look the same as they did on the outside?
      GQ7. Once the things a tree needs are inside, how are they used to make the tree grow?
      CQ3. What goes on inside a tree which results in its growth?
TABLE 3 (continued)

The constituent concepts for growth and the cell and their associated Protocol questions (GQ = Growth Protocol question, CQ = Cell Protocol question)

b. Animal

GQ14. When the things a person needs get inside the person, do they look the same as they did on the outside?
GQ15. Once the things a person needs are inside, how are they used to make the person grow?
CQ7. What goes on inside a person which results in his or her growth?

4. Instigation of growth

a. Plant

GQ9. What makes a tree start growing?
CQ4. What makes a tree start growing?

b. Animal

GQ17. What makes a person start growing?
CQ8. What makes a person start growing?

5. Cessation of growth

a. Plant

GQ8. What can cause a tree to grow poorly?
GQ10. Do all trees grow to be the same size?
GQ11. Do trees ever stop growing?

CQ5. Does a tree ever stop growing?

b. Animal

GQ16. What can cause a person to grow poorly?
GQ18. Do all people grow to be the same size?
GQ19. Do people ever stop growing?

CQ9. Does a person ever stop growing?
TABLE 3 (continued)

The constituent concepts for growth and the cell and their associated Protocol questions (GQ = Growth Protocol question, CQ = Cell Protocol question)

6. The cell as the basic structure of organisms (Cell Protocol only)

a. Cell differentiation

CQ10. Where do the different parts of an organism come from?
CQ13. Does the object or ones like it have anything to do with the beginnings of organisms?
CQ14. Does the object or ones like it have anything to do with the origins of different parts of organisms?

b. Cell identification and relation to growth

CQ11. What do you think the object is that the pointer is indicating?
CQ12. Does the object have anything to do with the drawings?

C. Cell interaction with body function

CQ14a. Does the object or ones like it have anything to do with how an organism works?
CQ19. What causes an organism to die?

7. The structure and function of the cell (Cell Protocol Only)

a. Identification of cell reproduction and relation to growth

CQ15. Do you think there is any relationship between anything in the photograph and what is happening in the drawing?
CQ17. Where do cells come from?

b. Cell control and metabolism.

CQ16. How does a cell work?
CQ18. What controls how a cell works?

c. Mitosis and meiosis

CQ20. What do you understand by the terms mitosis and meiosis?
TABLE 3 (continued)

The constituent concepts for growth and the cell and their associated Protocol questions (GQ = Growth Protocol question, CQ = Cell Protocol question)

8. Experience with growth in living things

GQ20. Do you remember ever growing plants in the classroom or at home, raising a pet, or having a baby brother or sister?

CQ21. Do you remember ever having studied growth or the cell in the classroom?

CQ22. Do you remember ever growing plants in the classroom or at home, raising a pet, or having a baby brother or sister?

One difficulty encountered in preparing the individual conceptual inventories from the transcripts was losing the context of the student's conception when the protocol question was no longer associated with the conception. In some cases, this required a modification of the verbatim form of the conception in the transcript. For example, the conception of the student below is difficult to interpret without the associated protocol question (I = Investigator, S = Subject, Lorraine, grade 5, 10 years, 8 months).

I: Once the water is inside the tree, how is it used to make the tree grow?

S: It gets crowded with it and rather than burst out when there's too much it pushes out on the bark and leaves and makes it grow.

In this student's conceptual inventory her conception under "use of requirements for growth by the organism" was stated as "Water goes into the plant and pushes out on the bark and
leaves. This makes it grow."

The subject's responses to the questions in the growth protocol related to the parameters of growth took the following form (Lorraine):

I: Look at these 4 drawings, what do you think is happening in them?
S: All the things are growing, they're growing, because they get bigger, but the rocks don't grow, there's just a bunch of rocks there.

I: How can you tell the things in the drawings are growing?
S: If you'd watch it for a while they'd all get bigger, taller, that's the way you know they're growing.

The student's conception as it was included in her individual conceptual inventory under the constituent concept "parameters of growth" took the form: "The tree, dog and person are growing because they are getting bigger. Rocks do not grow".

Another subject responded to the same set of questions in the following manner (Don, grade 3, Age 9 years, 1 month):

I: I've got 4 drawings here, what do you think is happening in them?
S: Oh, they're growing, plants grow, seeds, humans, all creatures, they grow.

I: What about this drawing, what is happening here?
S: Rocks don't grow, they're dead.

I: How can you tell the other things in the drawing are growing?

S: Growing things are living, other things that don't grow just stand there, they're dead, (pause) creatures have bodies that are working, things grow because they are alive.

In the individual conceptual inventory his conception was stated as "The tree, dog, and person, are growing because they are alive. Rocks do not grow because they are dead."

In all of these cases the subjects' conceptions were reconstructed to some extent, introducing the possibility of investigator bias. The problem facing most interview based studies lies in attempting to minimize this bias while at the same time reducing extensive transcribed data to a level which can address the research questions.

Pines' (1977) method of data analysis incorporated the protocol question and the student's statements into a propositional format, hence Conceptual "Propositional" Analysis. One of the drawbacks of this aspect of the analysis, noted in a critique of Pines' work by Posner and Gertzog (1983), is the possibility of children's responses becoming invested with phrases taken directly from the protocol. This was seen as misrepresenting the conceptions and increasing the possibility of incorporating investigator's interpretations directly into the data.
In this study, the priority was to stay as close as possible to the students' own words when representing their conceptions in the conceptual inventories. The reliability of this method of analysis was estimated using audio-tapes of pilot interviews with a student using the Growth Protocol and of another student using the Cell Protocol. Two copies of each tape were made. The criteria for compiling an individual conceptual inventory as described above was explained to a teacher and a business person. The two adults and the investigator then independently reduced the tapes to individual conceptual inventories. The 3 individuals identified 96 percent of the conceptions in the growth inventories as being in common and 94 percent of the conceptions in the cell interviews as being in common.

A number of sections of a student's individual conceptual inventory are presented below as a further example of this stage of analysis. The full transcription of Philip's interview is included as Appendix A and his complete individual conceptual inventory is presented in Appendix B. Both are used as a reference for the discussion. Numbers in the transcript correspond to the interview protocol questions. Philip was aged 9 years and 1 month and had not received any previous instruction in the concept of growth.

Philip's conception of the parameters of growth was stated as follows: "The tree, dog, person, and rock are
"growing because they change and get bigger." His idea that a rock is capable of growing is stated in his response to question 2:

I2: I have another picture here that I would like you to take a look at, have a look at this one (the rock picture) what do you think is going on in that picture? First of all, what do you think this thing is?

S: I think this is a rock on a beach ... first year it becomes a little rock ... when its 7 years it becomes ... bigger than it used to be ... Fifteen years later it becomes a boulder and 20 years later it becomes a huge rock that is big enough for a cave.

In response to two follow up questions, Philip maintains his idea:

I: Is there any of these pictures that is separate from the rest, that doesn't really fit?

S: They all show growing things.

I: And the rock is growing?

S: Yes, it is.

The conception includes "getting bigger" as a parameter of growth. There are extensive references to increase in size in the first part of the interview as illustrated in the following excerpts:

S: ... Two years later its almost a tree but not big enough yet ...

S: ... when its (rock) 7 years it becomes hugher, bigger
than it used to be ... 10 years later it becomes bigger ... 20 years later it ... is big enough for a cave.

S: First a puppy is like 3 or 4 months ... then 7 years later it becomes bigger and bigger ... and 25 years later its big enough for a pet.

I: What are the things that are happening to the tree or the person that are telling you it is growing?

S: Changes, like, it becomes bigger every time.

There are also references to change in characteristics other than size:

S: First, a seed is being buried ... later a plant starts growing and a root forms ... later it forms a tree.

S: You are first born a baby ... later you become a boy ... later you become a junior and go to high school ... later you become a man and go to work ... later you become a father of grandchildren ... 

S: First a puppy ... then it comes up to be a middle size puppy ... later it turns into a dog ... later it is big enough for a pet.

All three components, the growth of rocks as well as organisms, growth as an increase in size, and growth as change, have been included in the conception as it is stated in the Individual Conceptual Inventory.

Philip's conception related to the sources and acquisition of requirements for growth in plants is stated in his inventory as: "A tree needs a seed, roots, water, and
soil to grow. Water picks up the soil and brings it in through the roots. The water then goes to the branches."

This conception is stated in response to a number of protocol questions and follow-up questions:

I: Suppose we think about the tree for a moment, what do you think are the most important things a tree needs to grow?

S: It needs roots.

I: How about the same kind of question for a tree, what's important for a tree to grow?

S: Water, because if it doesn't have water ... it will die.

I: I see. Is there anything else you can think of that is important for the tree other than water?

S: The seed, because if you don't have a seed, the tree won't grow.

I: ... the stump ... when you look at the circles when you cut it open ... where do you think that stuff came from?

S: It came from the soil because when the water comes it actually goes into the soil that makes the roots pick it up and the soil gets into the water and the water lifts it to make the round circles when it grows.

I: So you think its the soil that gets in to make it (the inside of the tree)?

S: Yes it is, with the water.
Clearly, Philip's conception includes roots, seed, water, and soil as being important for plant growth. The following statements illustrate how he believes the water and soil are acquired by the tree:

I5: How do you think the water gets, does water get into the tree from somewhere, do you think?

S: Yes, once you pour water on the ground near a tree the roots pick it up from the ground and deliver it from branch to branch so the tree could grow.

I: But we've talked about the water getting in, right, what happens to it once it gets inside the tree?

S: Well, first the seed of the roots pick it up and then delivers it to a branch and once it gets to a branch the leaves pick it up and it keeps on growing until the trees get torn down by lumbermen.

A final example from Philip's Conceptual Inventory is his conception of the use of the requirements for growth in animals: "The food goes into your mouth and then in the neck it gets changed into 4 different food groups. It goes into your heart, and makes blood for the body. The blood pushes you up and makes you grow. The stuff you do not need goes out by veins." The following statements indicate Philip's beliefs regarding the fate of the requirements necessary for growth:

I: Ok, so you eat the food, put it in your mouth with a fork or spoon and what do you think happens to it then?
S: Then it goes, like, you chew it up and it goes into 3 groups and 4 groups and more groups and then forms into your body and the things you don't need comes, like, in a little vein that comes down, and if you don't need it then it comes out somewhere.

Il4: So what happens, like these 4 food groups you were telling me about, where does the food change into these 4 different groups?

S: Once you chew it, it changes around your neck or inside your neck.

I: And then once it is in, do you have any idea of what these 4 different kinds of groups are?

S: Just 4 plain groups of different kinds of stuff.

I: And then what happens to it once it forms 4 groups in your neck, where does it go then?

S: It goes down into your heart and makes blood for your body.

Protocol question 15 relates these statements to growth in the organism:

Il5: And then how does that make a person grow bigger?

S: Because if you have more blood you would, the blood would push yourself up and you keep on growing until your age, then you stop and die.

In order to provide a further illustration of this phase of the analysis, a further 3 examples from a second conceptual inventory for one of the grade 10 students are
presented below. The full transcription of the interview is included as Appendix C and the complete individual conceptual inventory is presented in Appendix D. Both are used as a reference for the discussion. Numbers in the transcript correspond to the interview protocol questions. Tracy was aged 15 years and 5 months and had recently completed a unit on the cell.

Tracy's conception of the parameters of growth was direct: "The tree and person are growing because their cells divide and make more cells. Size increases with growth."

This conception in her conceptual inventory is based on the following excerpts:

I: First off, I would like you to have a look at these two drawings here and tell me what you think is going on in them.
S: Growth.
I: Ok, anything you what to elaborate on?
S: The cells are dividing and that makes more cells, that is growth.
I: How about an organism you were not familiar with, like an ant, and you were asked as part of a project to figure out whether this thing was an adult or juvenile?
S: I would compare its size to other ones.
I: So size would be a characteristic?
S: Yes.

Tracy's conception of differentiation is more complex:
"A baby develops in the womb from a fertilized egg through the division of cells. The process is mitosis and I do not know where the different parts of the body come from." The conception is not self-contradictory. Tracy believes that the number of cells increases through cell division or mitosis:

I: What happens to that small fertilized egg in order to eventually develop into a person?
S: It grows because it is given food from the mother, it just grows inside the womb.
I: Do you know what happens to that cell to get all the cells that make up a person?
S: They divide.
I: So they all divide from the first one?
S: Yes.
I: Do you know the name of the process of that division?
S: Mitosis.
I: Are you sure of that?
S: Yes, we learned meiosis and mitosis.

Tracy then clearly shows that her conception does not include the idea that the cells change during development and that these changed cells result in the different parts of the organism:

I10: In nearly all cases, doesn't it have 2 eyes, 2 arms, 2 legs, how is that information packed in the cell?
S: I do not know.
I: Have you ever heard of the definition of mitosis as follows: the production of two identical daughter cells from one parent cell, is that correct?

S: Yes, and meiosis, it goes through mitosis twice.

I: Yes, let's stick to mitosis for a sec, ok, the production of two identical daughter cells from one parent cell, is that correct?

S: Yes.

I: Now, a person develops from that single fertilized egg into a full blown person by what process?

S: Well, mitosis, it sounds right and seems right to me.

I14: Well, if mitosis is only producing identical daughter cells, then how by mitosis do you think you can get liver, and heart, and kidney, and eyes, et cetera, et cetera?

S: I do not know.

I: Have you ever thought about that problem?

S: Yes I have but I do not know the answer. I do not think we learned it.

A final example involves Tracy's identification of a plant cell through the microscope. The specimen on the slide is an onion root tip, the same specimen used in the instructional unit on the cell. The questions are designed not only to investigate Tracy's ability to identify the cell but also to address her conception of how this microscopic cell relates to the macroscopic concept of growth. The
conception in her conceptual inventory with respect to the cell's relation to growth is "This is a plant cell because it seems in line. Everything living is made up of cells. The cells are growing, they are making more."

Question 11 and the follow up questions address the identity of the specimen:

I11: I would like you to have a look through the microscope here, ok, tell me what you think that thing is. If it's not in focus, use the bottom knob there.
S: It's a cell.
I: What kind of cell, any idea?
S: Um, a plant cell.
I: What makes you think it's a plant cell, anything in particular?
S: Oh, we did this in science, it looked like that.
I: What about it makes you say it is a plant and not an animal?
S: It seems so (pause) um (pause) like, in line, sort of thing, that's all.

The following series of questions and answers illustrate Tracy's conception of the cell and its relation to growth:

I12: Do you think cells have anything to do with the process that is going on in the drawing?
S: I think so, they are growing, they are making more.
I17: Do you think the only way something grows is making
more cells?
S: Yes, everything is made up of cells.
I: Are you sure all living things are made of cells?
S: Yes.
I: There is no parts of you that aren't made up of cells?
S: No.
I: How about other organisms? Do you think plants are made completely of cells?
S: Yes.
I: How about the bark, when you cut it open ...
S: It doesn't seem like it would, that is what I am thinking about, that is the only reason I would doubt it, because humans are all made up of cells, that's ok, but then you compare humans to bark, then it seems like (pause). It is still cells though.

Individual Conceptual Inventories were compiled from each interview transcript as described above. The method of organising these Individual Conceptual Inventories into a comprehensive form presenting all the students' conceptions as they related to specific constituent concepts is discussed in the next section.

4.1.2 The Compilation of Composite Conceptual Inventories From Individual Conceptual Inventories

After compiling Individual Conceptual Inventories for all students and interviews, these Individual Inventories
were then organised into what will be referred to as Composite Conceptual Inventories. Each constituent concept as outlined in Table 3 (Section 4.1.1) has a Composite Conceptual Inventory (henceforth CCI). Each CCI lists all of the students' conceptions related to a specific constituent concept. Construction of the CCIs involved 2 steps. Firstly, all Individual Conceptual Inventories (henceforth ICI) were compared and both similar and different conceptions were identified for each constituent concept. Secondly, the conceptions were listed according to their similarity to or difference from the scientific conception of the constituent concept in question. The development of the CCIs through the use of these 2 steps is discussed in more detail below.

In analysing the ICIs it was found that many of the students held similar conceptions with respect to many of the constituent concepts. For example, the conception "The tree, dog, and person are growing because they are getting bigger. Rocks do not grow" was identified in 6 ICIs of grade 3 students prior to instruction, 8 ICIs of grade 3 students after instruction, 8 ICIs of grade 5 students and 3 ICIs grade 7 students. A similar conception, "The tree, dog, and person are growing because they are getting larger" was identified in the ICIs of 7 grade 10 students prior to instruction and 4 grade 10 students after instruction. In the CCI summarizing Students' alternative conceptions of the parameters of growth these two conceptions were combined in
the form of the first one.

Conceptions were combined only if they were judged by the investigator to be similar in meaning. The conception "The tree and the person are growing because they are getting bigger because their cells divide, and the behaviour changes" was identified in 4 ICIs of grade 10 students. The conception "The tree and the person are growing because their cells divide and make more cells. Size increases with growth" was identified in the ICI of one grade 10 student. While both include cell division as a parameter of growth, the former includes behavioural changes while the latter includes changes in size. This difference was considered sufficient to include the conceptions separately in the CCI.

The second step in compiling the CCI was determining the order in which the students' conceptions would be listed. It was decided that the most useful approach in order to address the questions posed in this study would be to list them in a manner which represented their similarity to or difference from the scientific conception in question. This approach was first elaborated by Aguirre (1981) in analysing student conceptions with respect to certain vector characteristics.

Therefore, after all the conceptions related to a specific constituent concept had been identified, the content of each conception was compared to the characteristics of growth and the cell determined from the
concept analyses discussed in Chapter 3. The characteristics of growth (Table 1) and the cell (Table 2) were taken as the basic elements of a scientific conception related to the constituent concept in question. The conceptions were arranged from those least elaborated and least similar to the characteristics to those most elaborated and most similar.

It is important to recognize that this method does not offer an absolute "unscientific" to "scientific" scale. For example, the CCI of students' alternative conceptions of the parameters of growth include both the following conceptions:

1.1 The tree, dog, person, and rock are growing because they are getting bigger;

1.2 The tree, dog, person, are growing because their features are changing, they are getting bigger and look different. Rocks do grow.

Conception 1.1 was placed lower in the Inventory because it included one variable (getting bigger) while conception 1.2 contained two variables (getting bigger and features changing). Notice, however, that in both conceptions students saw rocks as growing.

Another example illustrating the difficulty often encountered in ordering the conceptions is found in the CCI containing conceptions of the sources and acquisition of requirements for growth in animals. The following are 3 of 14 conceptions identified with respect to that constituent
**concept:**

2B.5 People need food, water, and vitamins. They go in the mouth to the stomach;

2B.6 Animals need food, liquids, and sleep. The food and liquid goes to the stomach;

2B.7 People need vitamins, minerals, and nutrients. They get in through the mouth and go to the stomach.

In this example, the requirements included in all the conceptions together are necessary for growth. The 3 conceptions are difficult to distinguish on the basis of either their similarity to the characteristics of growth or the number of elements they contain. In this case the conceptions were loosely ordered on the basis of the complexity of the requirements.

Each CCI was titled according to the constituent concept of growth or the cell that it represented. Each conception in the list was given an identifier which contained a number, then in some cases a letter, then another number. The first number and letter correspond to the constituent concept number presented in Table 3. The second number indicates the position of the particular concept in the list. Thus the conception 2B.7 above is a conception related to the (2) Sources and acquisition of requirements for growth in (B) animals and occupies position (7) in the Inventory. The Composite Conceptual Inventory for the parameters of growth is listed as Table 4.
TABLE 4

Composite conceptual inventory of the parameters of growth

1.1 The tree, dog, person, and rock are growing because they are getting bigger.
1.2 The tree, dog, and person are growing because their features are changing, they are getting bigger and look different. Rocks do grow.
1.3 The tree, dog, and person are growing because they are getting bigger. Rocks do not grow.
1.4 The tree, dog, and person are growing because they are increasing in size but also changing in a predictable way in terms of appearance and characteristics.
1.5 The tree, dog, and person are growing because they are alive. Rocks do not grow because they are dead.
1.6 The tree, dog, and person have cells and change with time. They are growing. Rocks do not grow.
1.7 The tree and person are growing because their cells divide and make more cells. Size increase with growth.
1.8 The tree and person are growing because they are getting bigger because their cells divide, and their behaviour changes.

Each CCI was then organised in the form of a table. Each table includes the CCI as illustrated in the example in Table 4 and also the number of students holding each conception at the various grade and instructional levels included in this study. These tables represent the results
of this study and are presented and discussed in the next sections.

4.2 Alternative Conceptions of Growth

This section presents the results of this study as they relate to the concept of growth. Each of the subsections below presents the alternative conceptions held by students regarding a particular constituent concept of growth. Each subsection contains a table which represents the Composite Conceptual Inventory for the constituent concept. The table includes the alternative conceptions and the number of students holding the particular conceptions at the different grade and instructional levels.

The grade 3 level prior to instruction in growth is indicated by "3b" in each table, the grade 3 level after instruction by "3a". The grade 5 and 7 levels are indicated by "5" and "7" respectively. The grade 10 level prior to instruction in the cell is indicated by "10b" and after instruction by "10a".

With each table there is a short discussion which summarizes the results with reference to the following 4 key features:

1. The variability of the conceptions, expressed as the both the total number of alternative conceptions and the number of alternative conceptions identified in more than one ICI.
2. The existence of alternative conceptions in students prior to instruction in growth. These conceptions provide information regarding the extent and nature of the students' understanding of these ideas based on their own experience outside the classroom setting.

3. Patterns in alternative conceptions, that is, attempting to identify any major themes or categories within a particular constituent concept.

4. The identification of concept characteristics not represented in the conceptual inventories of the students.

4.2.1 The Parameters of Growth

Table 5 presents students' alternative conceptions of the parameters of growth in living things. Of the 8 alternative conceptions identified, 6 were found in more than one ICI. All of the students not yet having received instruction (3b) were found to hold alternative conceptions with respect to the parameters of growth (1.1 to 1.4) and in all cases these were identified again at other levels of instruction.

<table>
<thead>
<tr>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The tree, dog, person and rock are growing because they are getting bigger.</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Students' alternative conceptions of the parameters of growth</td>
<td>3b</td>
<td>3a</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------------------------------------</td>
<td>----</td>
<td>----</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1.2</td>
<td>The tree, dog, and person are growing because their features are changing, they are getting bigger and look different. Rocks do grow.</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1.3</td>
<td>The tree, dog and person are growing because they are getting bigger. Rocks do not grow.</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>1.4</td>
<td>The tree, dog, and person are growing because they are increasing in size but also changing in a predictable way in terms of appearance and characteristics.</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1.5</td>
<td>The tree, dog and person are growing because they are alive. Rocks do not grow because they are dead.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1.6</td>
<td>The tree, dog and person have cells and change with time. They are growing. Rocks do not grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1.7</td>
<td>The tree and person are growing because their cells divide and make more cells. Size increases with growth.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.8</td>
<td>The tree and person are growing because they are getting bigger because their cells divide, and the behaviour changes.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

The alternative conceptions were classified into three
general categories:

1. Growth is identified primarily as an increase in size (1.1, 1.3).
2. Growth is identified as an increase in size but also a change in appearance (1.2, 1.4).
3. Being alive is the primary parameter of growth (1.5).
4. Having cells is the primary parameter of growth (1.6).
5. Cell division is the microscopic explanation for growth at the macroscopic level (1.7; 1.8).

The majority of students at both the elementary and secondary levels, both before and after instruction, held conceptions categorized as 1 or 2 above. These students' conceptions tended to focus more on the macroscopic, observable features of growth rather than invoking cells. A microscopic explanation (4 or 5) was provided by 1 grade 7 student, 1 grade 10 student before instruction, and only 4 of the 20 grade 10 students after instruction in the cell.

4.2.2 The Sources and Acquisition of Requirements for Growth in Plants and Animals

Of the 16 alternative conceptions of sources and acquisition of requirements for growth identified in plants (Table 6), 12 were identified in more than one ICI. The increased variability found with respect to this constituent concept is accounted for by differences in the specific requirements necessary for growth, for example water and food (2A.5) as opposed to water and soil (2A.4).
Prior to instruction in grade 3, all students were found to hold alternative conceptions (2A.1 to 2A.7); only 2 students' conceptions were not found at a higher instructional level.

**TABLE 6**

*Students' alternative conceptions of the sources and acquisition of requirements for growth in plants*

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A.1</td>
<td>A tree needs a seed and water in order to grow.</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2A.2</td>
<td>A tree needs water and soil. This is the food for the tree. The food comes in through the roots.</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2A.3</td>
<td>A tree needs water and soil. This is the food for the tree. The water soaks in the trunk.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2A.4</td>
<td>A tree needs a seed, water, and soil to grow. Water picks up the soil and brings it through the roots. The water then goes to the branches.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2A.5</td>
<td>A tree needs water and food. The water comes in through the leaves and the food comes from the dirt through the roots.</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2A.6</td>
<td>A plant needs water and sunlight: The water goes in the roots and the sunlight through the leaves.</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2A.7</td>
<td>A tree needs a seed, sun, water, food, and soil to grow. The food and water comes in through the roots from the soil and goes to the leaves. The sunlight comes in the leaves.</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
TABLE 6 (continued)

Students' alternative conceptions of the
sources and acquisition of requirements
for growth in plants

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A.8</td>
<td>A tree needs a seed, air, light, and food, water and minerals. The air, food, water, and minerals come in through the soil, they are sucked up by the roots. The light shines on the leaves.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2A.9</td>
<td>Water, air, and sunlight get mixed together with soil to make food outside the plant. The food also comes from dead leaves and plants. The mixture then goes up the roots. Sunlight and oxygen are also used. I do not know how they get in.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2A.10</td>
<td>A plant needs sunlight, soil, water, and oxygen. They mix in the tree.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2A.11</td>
<td>A tree needs nutrition from the soil and energy from the sun and air. Energy is like electricity, you can not see it but you can feel it, and it enters the plant through the leaves. Nutrition is vitamins or minerals and water in the soil which the roots push up into the tree.</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2A.12</td>
<td>A plant needs light, water, and air. Water helps make sugar through photosynthesis.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2A.13</td>
<td>A tree needs water, sunlight and minerals. The water and minerals go in the roots. The plant collects sunlight in chlorophyll in the leaves and photosynthesis converts it into energy.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
### TABLE 6 (continued)

<table>
<thead>
<tr>
<th>Students' alternative conceptions of the sources and acquisition of requirements for growth in plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>3b 3a 5 7 10b 10a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2A.14</th>
<th>A tree needs water, sunlight, soil, and food. The water goes to the roots to make them grow. The sunlight shines on the chlorophyll in leaves and through photosynthesis makes food for the leaves and stem.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A.15</td>
<td>A tree needs water, sunlight and minerals. The water keeps the tree from drying out and goes in the roots. The sunlight shines on the chlorophyll in leaves and through photosynthesis makes food for the plant.</td>
</tr>
<tr>
<td>2A.16</td>
<td>A plant needs light, water, nitrogen, nutrients and minerals in the soil. The water takes in the nitrogen, nutrients and minerals through the roots. Light is converted by the cells of the leaves into glucose or sugar by photosynthesis.</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

These alternative conceptions were grouped into 4 broad categories:

1. Water and soil are the food of the tree and come in from the outside, move through the roots, and up into the branches and leaves (2A.1 to 2A.5).

2. Water and soil are the food for the tree and come in from the outside, move through the roots, and up into the branches and leaves. Light has a secondary
function (2A.6 to 2A.9).

3. The material that enters the tree is changed and this changed material is food for the tree. The sun is involved in a general sense and enters through the leaves (2A.10 to 2A.11).

4. The material that enters the tree is all necessary for growth, but sunlight involved somehow with photosynthesis is the most important (2A.12 to 2A.16).

Prior to instruction in grade 3, all students were found to hold conceptions falling in categories 1 or 2. The majority of other students at the elementary levels were also identified in these categories. Roughly 50 percent of the students at the grade 10 level, both before and after instruction in the cell, held conceptions falling in these two categories. Six students at the grade 7 level, 5 in grade 10 before instruction and 4 students after fell into category 4. A close examination of the conceptions in this category reveals, however, a variety of ideas concerning photosynthesis. None of the conceptions could be called a strictly scientific conception because even the most elaborate (2A.16) does not link nutrients and water with the process of photosynthesis.

Water is seen as the primary element in nearly all the conceptions while sunlight is in most cases secondary. While air (2A.8, 9, 11, 12) and oxygen (2A.9, 2A.10) are mentioned as necessary requirements, there appears to be no conception
which includes oxygen or carbon dioxide as vital components in the growth of plants.

There were 14 student conceptions for the sources and acquisition of requirements for growth in animals, of which 12 were identified in more than 1 ICI (Table 7). Again, most of the variability is accounted for by the specific elements required for growth, for example, food, water and exercise (2B.4) as opposed to food, water, and vitamins (2B.5).

All students were found to hold conceptions prior to instruction in grade 3 and these conceptions were identified at higher instructional levels with one exception, the conception which stated that food goes from the mouth to the heart (2B.1).

TABLE 7

<table>
<thead>
<tr>
<th>Students' alternative conceptions of the sources and acquisition of requirements for growth in animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>3b 3a 5 7 10b 10a</td>
</tr>
<tr>
<td>2B.1 Animals need healthy food and exercise. The food goes to the heart.</td>
</tr>
<tr>
<td>2B.2 People need sleep, food and exercise. The food goes down your esophagus and then changes.</td>
</tr>
<tr>
<td>2B.3 Animals need food and water. The food includes vegetables, fruit, and meat. The food and water go in the mouth to the stomach.</td>
</tr>
</tbody>
</table>
**Students' alternative conceptions of the sources and acquisition of requirements for growth in animals**

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B.4</td>
<td>Animals need food, water, and exercise. The food includes vegetables, fruit and meat. The food and water go in the mouth to the stomach.</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2B.5</td>
<td>People need food, water, and vitamins. They go in the mouth to the stomach.</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2B.6</td>
<td>Animals need food, liquids and sleep. The food and liquid goes to the stomach.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2B.7</td>
<td>People need vitamins, minerals, and nutrients. They get in through the mouth and go to the stomach.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2B.8</td>
<td>Animals need food, liquids, exercise, love, and exercising our mind. The food enters the mouth and is broken down into smaller bits before it goes to the stomach.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2B.9</td>
<td>Animals need water, food, sunlight and oxygen to breath. The food goes to your stomach and the oxygen to your lungs. I do not know what happens to them after that.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2B.10</td>
<td>Animals need food, water, shelter and care. The food goes to your stomach and is changed to energy. This energy is distributed to the body by the blood.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
TABLE 7 (continued)

Students' alternative conceptions of the sources and acquisition of requirements for growth in animals

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B.11 Animals need food from the four food groups and water. It goes to the stomach, the nutrients go to the blood and the wastes get excreted.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2B.12 Animals need food, water, exercise and air. The air is for breathing, the food supplies your cells, and the water clears you out.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2B.13 Animals need food, water, emotional support and oxygen, which you need to breath. The food goes to the stomach and then the intestines. The part your body needs goes to white blood cells, red blood cells do something else. The white blood cells deliver food to other cells.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2B.14 Animals need food and water and psychological things like love and care. The food and water begin being decayed in the mouth and stomach acids cause further decomposition. The villi in the intestines take the nutrients and put them in the blood. The blood supplies the nutrients to the cells all over the body. Psychological things can affect physical things like obesity.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

These conceptions represent a wide variety of beliefs regarding the specific elements necessary for growth. Two more general categories can be identified, however, based on
where the requirements eventually end up:

1. Food and water are the primary requirements for growth. These go from the mouth to the heart, esophagus, or stomach (2B.1 to 2B.9).

2. Food and water are the primary requirements for growth. These go from the mouth to the stomach, are then changed, and then go to the body (2B.10 to 2B.14). Alternative conception 2B.3 best represents category 1, and the majority of the students in the sample are represented by it. All of the elementary students were identified in this category. The conceptions listed under category 2 were held by 8 grade 10 students prior to instruction, and 4 grade 10 students after instruction. Of the other requirements for growth, exercise appears to be an important one (2B.1, 2B.2, 2B.4, 2B.8, 2B.12).

As in the case of plants, while gases are included in a few conceptions (oxygen to the lungs, 2B.9; oxygen which you need to breath, 2B.13) by a minority of students, there is no mention of the necessity of respiration for growth in animals.

4.2.3 The Uses of the Requirements for Growth by Plants and Animals

Of the 20 alternative conceptions of the uses of the requirements for growth in plants (Table 8), 12 were identified in more than one ICI. Roughly 40 percent of the
students at the elementary level and 20 percent at the secondary level stated that they had no conception regarding this constituent concept (3A.1). In the latter group this applied both before and after instruction.

Six of the 11 grade 3 students held conceptions regarding the uses of the requirements for growth by plants before instruction.

### TABLE 8

**Students' alternative conceptions of the use of requirements for growth by plants**

<table>
<thead>
<tr>
<th>Conception</th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A.1 I do not know how the plant grows.</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3A.2 The sunlight bathes the tree, keeping it warm and preventing it from freezing. I do not know how the other things make the tree grow.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.3 The sun gives the plant heat to grow. The water makes the tree grow in size. I do not know how.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3A.4 The sunlight gives the plant colour and vitamins. I do not know what the water and soil do.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3A.5 The sun prevents the tree from getting too wet, it dries it out by shining on the leaves. There is brown stuff in the tree which tells how old it is and there is also sticky water or syrup. I do not know how the food and water gets changed into this. I do not know how they make the tree grow.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3b</td>
<td>3a</td>
<td>5</td>
<td>7</td>
<td>10b</td>
<td>10a</td>
</tr>
<tr>
<td>---</td>
<td>----</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>3A.6</td>
<td>The water goes up the roots and gets carried to the leaves to make them expand and grow. The sunlight attracts the plant in the direction it will grow, usually up.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>3A.7</td>
<td>The plant uses the water to keep from drying out. More water goes into the plant and pushes out the bark. This makes the tree grow. The sun gives the tree vitamins. It gives the tree better colour and makes it healthier because the ones we put in the dark grew but were white. The sun gives the plant a tan.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.8</td>
<td>The plant puts the water and food in the roots, trunk, and leaves. As more comes in, it pushes out and makes the tree grow. The water keeps the tree from drying out.</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.9</td>
<td>The root pushes the tree up. The stuff in the soil makes the root and it turns into wood and keeps pushing up.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.10</td>
<td>The sun's heat expands the leaves and trunk. The water changes into a liquid in the veins of the trunk and fills out the expanded trunk and leaves.</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.11</td>
<td>The tree uses water to make honey or syrup. The soil then makes these rings in the plant. The rings get more every year, this is how the plant grows. The syrup is also important.</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 8 (continued)

Students' alternative conceptions of the
use of requirements for growth by plants

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A.12</td>
<td>The plant uses the soil and water to make milk. Circles and veins in the tree carry this milk to all the parts of the tree. It fills up and makes the tree bigger.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3A.13</td>
<td>The plant uses energy from food to grow. I do not know how. The plant uses water to keep cool. I do not know how they make the tree grow.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.14</td>
<td>The plant mixes the Vitamin C in sunlight with the water and makes food. The food is delivered to plant parts, which grow bigger. They do not have cells.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3A.15</td>
<td>The plant uses energy from the sun and minerals to feed itself. I do not know how. The experiment showed that the ones without light and minerals did not grow as well. The water pushes the tree out and keeps it from drying out.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.16</td>
<td>Photosynthesis through sunlight breathes in carbon dioxide and breathes out oxygen. The minerals nourish the tree. I do not know how it grows.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3A.17</td>
<td>The water and minerals allow the cells to divide and get bigger. The sunlight keeps the plant green.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 8 (continued)

Students' alternative conceptions of the use of requirements for growth by plants

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A.18 The plant distributes the water and minerals all over. Minerals are what the tree is built of. They supply the cells so they can split and let the tree grow. Photosynthesis absorbs sunlight.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3A.19 Photosynthesis chemically turns the water and food from the soil into the type of food the tree needs to grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3A.20 The minerals and water from the roots combines with the energy from the photosynthesis of the sun and this just makes the plant grow bigger and bigger.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3A.21 The water from the roots combines with the food from the photosynthesis of sunlight to make the plant grow by making more cells.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

These conceptions can be grouped into 5 broad categories:

1. Materials, primarily water, go into the plant and push out on the parts causing them to expand or grow (3A.6 to 3A.8).
2. Materials change into something else when they are in the plant and make it grow (3A.9 to 3A.14).
3. Photosynthesis is responsible for growth in plants (3A.15, 3A.19, 3A.20).
4. Cell division is responsible for growth in plants (3A.17, 3A.18).

5. Photosynthesis supplies the food necessary for cells to divide which results in the growth of the plant (3A.21).

The conceptions held by students in grade 3 prior to first instruction fell into category 1 or 2. Three grade 7 students, 5 grade 10 students before instruction and 7 grade 10 students after instruction in the cell suggested that photosynthesis had something to do with growth in plants. Less than half of these students appeared to hold a clear conception of how photosynthesis contributes to growth.

Conception 3A.21 closely resembles the scientific conception of the use of requirements for growth in plants although it does not specify how more cells are created. This conception was held by 1 grade 7 student, 3 grade 10 students before instruction and 3 grade 10 students after instruction in the cell. The conception that cell division is an explanation for growth in plants (4 and 5 above) was identified in 15 percent of the grade 10 students before instruction and 25 percent after instruction in the cell.

With respect to students' conceptions of the use of the requirements for growth by animals (Table 9), 16 of the 22 alternative conceptions were identified in more than 1 ICI. Not more than 4 students at any grade level lacked a conception of this constituent concept. Seven grade 3
students were found to hold conceptions prior to instruction; only 1 held a conception that was not identified at another instructional level.

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3B.1</td>
<td>I do not know.</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3B.2</td>
<td>The food in your stomach goes to your legs, arms, all over. It makes all of these bigger.</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3B.3</td>
<td>The food goes to the stomach and then to the heart. The heart pumps it around to everywhere, like your hands.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.4</td>
<td>The food goes into your stomach and makes fat, and this adds on to you to make you bigger.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.5</td>
<td>The nutrients get broken up in the digestive system and distributed to all the parts. The parts take in the nutrients and just get bigger.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.6</td>
<td>The food in your stomach goes through cords to your bladder and bones. The bones grow when more food is inside pushing the bones out. This pushes the skin out and everything else gets pushed out too so you grow.</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3B.7</td>
<td>The food goes into the stomach which breaks it into smaller pieces. It then goes to the bones and legs and other parts and sort of sinks into them. The food pushes the skin in your arm outward and it gets bigger. If it is junk food, it is just fat.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
### TABLE 9 (continued)

**Students' alternative conceptions of the use of requirements for growth by animals**

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3B.8 Once the food is in the stomach, the stomach makes minerals from it and takes out proteins and fats. The minerals go by veins to the bones and make them bigger. The other things go to soft parts and make them bigger.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.9 The water supplies your stomach with minerals, foods have the vitamins. Candy gives you sugar. The stomach makes this stuff into protein and puts it in the blood. The protein then goes to your body.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.10 The food gets broken down in the mouth and stomach and goes into the intestinal system. The nutrients get taken out and turned into a liquid. This liquid goes through your body and delivers nutrients to your bone marrow which gets bigger causing you to grow. The liquid then goes by the intestines which takes out the wastes.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.11 The nutrients go from your digestive system to the blood. I do not know how they make you grow.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3B.12 The food changes when it gets to the stomach. Energy from the food goes to the heart which pumps blood to the brain. The brain makes the muscles and bones grow. Your skin stretches and you grow until you have reached your proper size.</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
### TABLE 9 (continued)

**Students' alternative conceptions of the use of requirements for growth by animals**

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3B.13</td>
<td>The nutrients go from the blood to the bones and make the bones bigger.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>3B.14</td>
<td>The stomach uses the food and liquids to make blood. The blood goes to all your parts. The vitamins in the blood make your bones grow, and you get stretched out, so you grow.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3B.15</td>
<td>The food and water go into your mouth and get changed into 4 different food groups. It goes into your body, to your heart and makes blood for the body. The blood sort of pushes out your parts and makes them grow. The stuff you do not need goes out by veins.</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.16</td>
<td>The nutrients go from your digestive system to the blood. The blood brings the nutrients to the muscles which expand and make you grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3B.17</td>
<td>The nutrients go from the stomach to the blood. From there they go to the cells. I do not know how they contribute to growth.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3B.18</td>
<td>The food goes into the digestive system. It is broken down and the vitamins and minerals are put into the blood. The rest is waste. The vitamins and minerals go to your cells in all the parts of your body and make them bigger and bigger.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 9 (continued)

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3B.19 The food goes into the digestive system. The bones grow because there are more cells. The skin stretches as the bones grow. I do not know how the cells are made.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.20 The food is digested, the cells break down the food into small enough pieces so they fit through the cell membrane. The cell membrane then gives off energy which goes into the blood. This energy makes more of all kinds of cells and makes the body grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B.21 The nutrients in the digestive system supply the body with energy. The energy supplies the cells and they divide, and you grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>3B.22 The nutrients go from your digestive system to the blood. They then go to the cells and lets them divide.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3B.23 The nutrients go from the digestive system to the cells. The cells then divide and grow. This causes the body to grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11</strong></td>
<td><strong>11</strong></td>
<td><strong>18</strong></td>
<td><strong>10</strong></td>
<td><strong>20</strong></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>

Four broad categories were identified in this area:

1. Food and liquids go into the body forcing it outwards and increasing its size (3B.2 to 3B.9).
2. The materials upon entering the body are changed into blood, which causes the muscles and/or bones to grow.
stretching out the skin, or pushing out the parts (3B.10 to 3B.17).

3. The nutrients in the blood supply the cells which grow bigger or somehow increase in number, causing the bones to grow and the parts to get bigger (3B.18 to 3B.20).

4. The nutrients supply the cells with energy allowing the cells to divide, creating more cells, and thereby growth (3B.21 to 3B.23).

Students in grade 3 prior to instruction fell primarily into category 1. The conceptions at the other elementary levels fell mainly into categories 2 and to a lesser extent 3. The conception that cell division is responsible for growth in animals was stated by 5 grade 10 students prior to instruction and 14 of 20 after instruction. Conception 3B.23 could be considered as a basic scientific conception of growth in animals. It includes both cell division and the growth of individual cells. One student held this conception prior to and after instruction in grade 10. A second student held this conception prior to instruction but stated conception 3B.22 after instruction. The latter conception does not include the notion of cell growth.
4.2.4 The Instigation of Growth in Plants and Animals

Of 10 alternative conceptions identified with respect to this constituent concept (Table 10), 8 were found in more than 1 ICI. Only 4 students were found to have no conception of the instigation of growth in plants. Of the 11 grade 3 students, 9 were found to have conceptions in this area prior to instruction, of which one students' was not identified at another level of instruction.

<table>
<thead>
<tr>
<th>TABLE 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students' alternative conceptions of the instigation of growth in plants</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>3b</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>4A.1 I do not know.</td>
</tr>
<tr>
<td>4A.2 The seed knows inside when it is time to grow.</td>
</tr>
<tr>
<td>4A.3 Spring (the seasons) tells the seed it is time to start to grow.</td>
</tr>
<tr>
<td>4A.4 The dirt goes into the seed, the food, and it starts growing.</td>
</tr>
<tr>
<td>4A.5 Plants start as a seed. Put the seed in soil and it will grow.</td>
</tr>
<tr>
<td>4A.6 A tree starts as a seed. The amount of sunlight the seed gets will cause it to grow.</td>
</tr>
<tr>
<td>4A.7 Plants start as parts cut or fallen off other plants. These get in the soil and grow.</td>
</tr>
</tbody>
</table>
TABLE 10 (continued)

**Students' alternative conceptions of the instigation of growth in plants**

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>4A.8</td>
<td>Plants start as a seed. Water the seed and the tree starts growing.</td>
<td>4</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>4A.9</td>
<td>Water cracks the seed open and lets the roots out. They suck up food and water and the seed starts to grow.</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4A.10</td>
<td>Plants start as a seed. Water and sunlight makes the seed start growing.</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4A.11</td>
<td>A plant starts as a group of cells making up a seed. When water gets to the seed, the cells develop into the different parts of the tree.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

N =

11 11 18 10 20 20

The 11 conceptions above were grouped into 4 categories:

1. Plants start as seeds and need things not including water to grow (4A.2 to 4A.6).

2. Plants start as parts cut off or fallen off of other plants. These get in the soil and grow (4A.7).

3. In order for plants to begin to grow, a seed need only be supplied with water (4A.8).

4. In order for plants to begin to grow, a seed needs water and other requirements (4A.9 to 4A.11).

A substantial portion of the sample was identified in category 3 in which water was seen as the only necessity for
growth. This category represented over 50 percent of the grade 10 students both before and after instruction. A number of students at the elementary level added sunlight to this conception (4A.10).

Category 2 represents 2 students who saw growth occurring only through vegetative reproduction (4A.7). In grade 10, the cell was identified as component of the instigation of growth in plants in only 4 ICIs out of 40.

At the grades 5, 7, and 10 level, follow up questions were posed to students in order to determine if they held any conceptions regarding the state of the seed before it germinated. A CCI was prepared for these alternative conceptions and is presented in Table 11. The grade 3 students were not asked the follow up questions, therefore they are not included in the sample.

TABLE 11

<table>
<thead>
<tr>
<th>Students' alternative conceptions</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>4E.1 I do not know.</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>4E.2 Seeds are dead. When you plant them in soil, then they become alive.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4E.3 Seeds are non-living. Rocks are dead, they can not grow. Seeds can grow so they are non-living when they are not growing yet.</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>4E.4 Seeds are not dead, alive, or non-living. They are hibernating until they get water. They then come alive.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 11 (continued)

Students' alternative conceptions regarding the nature of the seed in plants

<table>
<thead>
<tr>
<th></th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>4E.5 A seed is dormant when it is not growing. It is asleep but alive.</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4E.6 A seed is alive. It just does not grow until the conditions are right.</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

N = 10 10 20 20

A number of students had no conception of the nature of the seed before germination (4E.1). The conceptions that were identified were separated into 3 categories:

1. Seeds are non-living when they are not growing (4E.2, 4E.3).
2. Seeds are dormant when they are not growing (4E.4, 4E.5).
3. Seeds are alive when they are not growing (4E.6).

The majority of ICIs at all levels fell into category 1. Fourteen of the 20 grade 10 students held this view after instruction. This particular conception will be examined in more detail in the discussion section (4.4) of this chapter. Only a minority of students held a conception of the seed as being alive.

More alternative conceptions were identified with respect to the instigation of growth in animals than in plants. Of the 17 alternative conceptions identified with respect to animals (Table 12), 11 were found in more than 1
ICI. Very few students held no conceptions in this area (4B.1). Nine of the 11 grade 3 students were found to hold conceptions prior to instruction of which only 1 student's conception was not identified at another grade level.

<p>| TABLE 12 |
|------------------|---|---|---|---|---|---|
| Students' alternative conceptions of the instigation of growth in animals |
| 3b | 3a | 5 | 7 | 10b | 10a |
| 4B.1 I do not know. | 2 | 4 | 2 | 0 | 0 | 0 |
| 4B.2 The baby gets fatter and fatter in the mother. The mother knows the time the baby is going to come. | 1 | 0 | 0 | 0 | 0 | 0 |
| 4B.3 The baby is in the mother's stomach. When the mother eats, the baby eats some of the food, it gets bigger and when it gets too big the mother goes to the hospital and the baby comes out. Then at every birthday you grow a little bit more. | 2 | 3 | 4 | 2 | 0 | 0 |
| 4B.4 A person starts as a baby. Food makes the baby start growing. | 4 | 3 | 5 | 1 | 0 | 0 |
| 4B.5 The baby is in the mother. A cord connects the mother to the baby and food goes into the baby pushing out its parts and making it bigger. Smoke does too. | 1 | 0 | 1 | 0 | 0 | 0 |
| 4B.6 The organism starts in the mother with very very small bones. As food is supplied, the organism grows. | 0 | 0 | 0 | 0 | 1 | 0 |
| 4B.7 A person begins as one cell. The cell divides by meiosis to form a person. | 0 | 0 | 0 | 0 | 0 | 1 |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4B.8</td>
<td>A person starts as a egg in the mother. When the mother eats food the baby gets bigger.</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>4B.9</td>
<td>The baby starts in the mother's womb as an egg. The baby is connected to the mother by an umbilical cord which passes food from mother to baby. The food goes into the baby's body and makes it grow.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>4B.10</td>
<td>A person begins in the mother as an egg with cells for all parts of your body. These divide to make the parts.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4B.11</td>
<td>A person begins as one cell. The cell divides by mitosis to form a person.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4B.12</td>
<td>An egg that becomes fertilized becomes and embryo, a baby. It grows because it is given food from the mother, it grows inside the womb.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4B.13</td>
<td>A person begins in the mother as a fetus, the result of an egg being fertilized by a sperm. I do not know how it grows.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4B.14</td>
<td>A person is conceived by a man and a woman. It starts as a fertilized egg in the mother's womb. Minerals from the mother make it grow bigger and bigger.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
**TABLE 12 (continued)**

*Students' alternative conceptions of the instigation of growth in animals*

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>4B.15</td>
<td>The egg is small and round and has many small parts. The mother supplies it with food and the parts develop. The parts are originally made by the genes of the mother and father.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4B.16</td>
<td>Two cells, one from each parent, make an embryo made up of special cells that are present at the beginning from the characteristics of your parents.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4B.17</td>
<td>A person begins in the mother as a fertilized cell. Chromosomes tell the cell what to do. I do not know how.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4B.18</td>
<td>A person begins as the result of the fertilization of an egg by a sperm. A zygote forms which has a large food supply. It divides many times before the mother supplies nutrition.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

Four major categories of conceptions were identified:

1. A person starts life as a baby in the mother and is supplied with food (4B.2 to 4B.6).
2. A person starts life as an egg, food is supplied by the mother (4B.7 to 4B.11).
3. A person starts life as an egg fertilized by a sperm, food is then supplied by the mother (4B.12 to 4B.17).
4. A person results from an egg being fertilized by a
sperm, which then grows as a result of division nourished by nutrients from the mother (4B.18).

All but one of the conceptions of students prior to instruction and the majority of conceptions at the elementary level as a whole fall under category 1. An interesting conception in this category states that the baby is actually in the mother's stomach (4B.3). This conception was identified in 11 ICIs, 2 of which were at the grade 7 level. A number of students at the grade 10 level stated that it was necessary for the egg to be fertilized in order to begin growth (categories 3 and 4). Only 1 student at the elementary level stated this.

The involvement of cells in the instigation of growth is indicated in 2 grade 10 ICIs prior to instruction and 3 grade 10 ICIs after instruction. The conception which most clearly represents category 4 is conception 4B.18 in which the zygote is seen as dividing, rather than cells. This was held by one student before instruction in grade 10.

A clear notion of cell differentiation, that is, the development of different cell types from the original fertilized egg, was not found in any of the ICIs. Attempts at explaining the development of a complex organism from a single simple egg or cell were evident, however. The most frequent idea invoked in this regard was that the complete complement of cells or parts were already present in the egg when it began growth. Some examples include "the organism
starts ... with very small bones" (4B.6), " ... begins ... with cells for all parts of your body" (4B.10), or " ... made up of special cells that are present at the beginning ..." (4B.16).

4.2.5 The Cessation of Growth in Plants and Animals

Of the 15 alternative conceptions of the cessation of growth in plants (Table 13), 13 were identified in more that 1 ICI. An "I do not know" response was identified in only 2 ICIs although a greater number of students, after stating that trees stopped growing, did not have a reason as a component of their conception (5A.2). Ten of the 11 grade 3 students held conceptions prior to instruction.

TABLE 13

Students' alternative conceptions of the cessation of growth in plants

<table>
<thead>
<tr>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A.1 I do not know.</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5A.2 Trees stop growing. I do not know why.</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5A.3 Trees and plants stop growing because they just cannot get too big.</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5A.4 Trees will not stop growing, until the dinosaurs return and knock them down.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5A.5 Trees never stop growing except when they hibernate over winter.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5A.6</td>
<td>Plants reach a certain height and then stop growing. It depends on where they are planted.</td>
<td>0 0 0 0 2 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.7</td>
<td>Plants will continue to grow, but conditions always change so eventually they die.</td>
<td>0 0 0 0 2 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.8</td>
<td>Trees stop growing. There are differences in size because they receive different amounts of the things they need. I do not know what makes them stop growing. The tree goes on living after it stops growing.</td>
<td>2 1 3 1 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.9</td>
<td>Trees and plants stop growing upwards at a point but continue to grow new parts. I do not know why.</td>
<td>0 0 0 1 7 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.10</td>
<td>Trees stop growing. The things they took in are then used to make new leaves.</td>
<td>1 1 1 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.11</td>
<td>Trees stop growing, they use the materials to stay alive.</td>
<td>1 2 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.12</td>
<td>Trees do not stop growing, they grow very slowly. Trees are different sizes because the seeds are different.</td>
<td>0 0 3 0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.13</td>
<td>Plants will continue to grow until the chromosomes tell the cells to stop dividing. Then they will just live.</td>
<td>0 0 0 0 1 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.14</td>
<td>Plants stop growing when their cells stop dividing.</td>
<td>0 0 0 0 0 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A.15</td>
<td>Plants continue to grow until they die.</td>
<td>1 1 4 3 5 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 13 (continued)

**Students' alternative conceptions of the cessation of growth in plants**

<table>
<thead>
<tr>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A.16 Plants stop growing when their cells die.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ N = 11 \quad 11 \quad 18 \quad 10 \quad 20 \quad 20 \]

The above 16 conceptions were grouped into four categories:

1. Plants stop growing in an upward direction for a variety of reasons (5A.2 to 5A.11).
2. Plants do not stop growing, they grow slowly (5A.12).
3. Plants stop growing when cells stop dividing (5A.13, 5A.14).
4. Plants stop growing when they or their cells die (5A.15, 5A.16).

The majority of students held alternative conceptions in category 1. Seven students at the grade 10 level were found to hold conceptions in category 3 after instruction. This is an interesting alternative conception because cell division is seen as occurring only so long as an organism is growing. It does not include the notion that cells are continually dividing thereby replacing cells that die.

Students at all levels held conceptions in category 4, at the grade 10 level, 6 before instruction and 4 after.

Fifteen alternative conceptions of the cessation of growth in animals were identified (Table 14), all of which
were found in more than 1 ICI. As in the case of the cessation of growth in plants, a substantial number of students stated that growth in animals stopped, but offered no mechanism. Ten of the 11 grade 3 students were found to hold conceptions prior to instruction.

| TABLE 14 |
|---|---|---|---|---|---|---|
| Students' alternative conceptions of the cessation of growth in animals | 3b | 3a | 5 | 7 | 10b | 10a |
| 5B.1 I do not know. | 1 | 1 | 1 | 0 | 0 | 0 |
| 5B.2 People stop growing in height but they go on living. I do not know why. | 3 | 6 | 2 | 0 | 11 | 1 |
| 5B.3 People stop growing. They know they can not get too big. | 1 | 0 | 3 | 0 | 0 | 0 |
| 5B.4 People stop growing. They use the materials to stay alive. | 1 | 2 | 1 | 0 | 0 | 0 |
| 5B.5 People stop growing when they get old and then they get smaller in size. There are differences in sizes of people because there are differences in what they eat and how they exercise. You do not continue to grow because your skin could not hold you. A person goes on living for a time after he stops growing. | 2 | 1 | 5 | 1 | 0 | 0 |
| 5B.6 People stop growing. The food then makes them fatter unless they exercise and use it for that. | 0 | 1 | 1 | 0 | 0 | 0 |
| 5B.7 People stop growing when they get old. I do not know why. People grow to different sizes because they take after their fathers and mothers. | 0 | 0 | 1 | 5 | 0 | 0 |
### TABLE 14 (continued)

**Students' alternative conceptions of the cessation of growth in animals**

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>5B.8</td>
<td>People stop growing when they get old because the bones get too old and can not grow. There are differences in size of people because their mothers are different or they do not get the same exercise.</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>5B.9</td>
<td>People stop growing when they get old and their heart stops, then they die. People grow to different sizes because some exercise their bodies or work while others do not.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5B.10</td>
<td>People never stop growing in size, it just gets slower. People grow to different sizes because of differences in the family.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5B.11</td>
<td>People stop growing but do not die. The food used for growing before just keeps the bones strong. The brain sends the message for when it is time to stop growing.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5B.12</td>
<td>People stop growing at a point. It is controlled by chromosomes and genes.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>5B.13</td>
<td>People stop growing but they go on living. This is because cells reproduce rapidly as you are growing and then slow down and stop when you have reached your appropriate height.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>5B.14</td>
<td>People stop growing only when they die.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 14 (continued)

Students' alternative conceptions of the cessation of growth in animals

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>5B.15 People stop growing when their cells get overworked. Your system will begin to break down.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5B.16 People never stop growing because their cells are always being replaced by mitosis. Only brain cells are not replaced.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

Four categories were identified:

1. Animals stop growing for some reason but go on living (5B.2 to 5B.10).

2. Animals stop growing, and this is controlled by something in the animal. Animals then go on living (5B.11, 5B.12).

3. Animals stop growing when the cells stop dividing (5B.13).

4. Animals do not stop growing until they die (5B.14, 5B.15, 5B.16).

In the first category, exercise (5B.5), work (5B.6, 5B.9), and or parents (5B.7, 5B.10) are cited as influencing the cessation of growth. Control in category 2 can be by the brain (5B.11), chromosomes or genes (5B.12), or by overworked cells (5B.15).

Category 3 is composed of 1 alternative conception, namely 5B.13. This conception, that growth stops when the
cells stop dividing, was also found with respect to plants. In this case, 50 percent of the grade 10 students after instruction held this conception.

The conception expressed in 5B.16 closely approximates a scientific conception with respect to the cessation of growth in animals. It was identified in only 2 ICIs, both after instruction in the cell at the grade 10 level.

4.2.6 Students' Experience With the Growth of Organisms

Students were asked about their experience with growing things. Table 15 summarizes the responses of all the students at all instructional levels. Of the students interviewed prior to any instruction at the grade 3 level, only 2 of 11 reported having no experience with growing things at all. The other 9 reported experience with growing things at home (8.2) but not at school. After instruction at the grade 3 level, the majority of students at all levels reported experience with growth at home and at school.

With respect to students' knowledge of the cell, only 1 of 18 grade 5 students stated that they had heard of it. Two of those in grade 7 and 8 of 20 in grade 10 prior to instruction reported the same. None, however, stated that they had learned about the cell as a lesson at school. This changed for all 20 students at the grade 10 level after instruction (8.5).
TABLE 15

Students' report of experience with growth of living things

<table>
<thead>
<tr>
<th></th>
<th>3b</th>
<th>3a</th>
<th>5</th>
<th>7</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>No experience with growing things at home or school. Do not know about the cell.</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8.2</td>
<td>Experience with growing a plant or an animal at home. None at school. Do not know about the cell.</td>
<td>9</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>8.3</td>
<td>No experience with growing things at home. Grew a plant at school. Do not know about the cell.</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8.4</td>
<td>Experience with growing a plant or an animal at home and grew a plant at school. Do not know about the cell.</td>
<td>0</td>
<td>9</td>
<td>14</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>8.5</td>
<td>Experience with growing a plant or an animal at home and grew a plant at school. Have heard of the cell.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

N = 11 11 18 10 20 20

As an addition to the cell protocol, students at the grade 10 level were asked about their experience with growing things in a classroom environment. The results of the students' responses are summarized in Table 16. While a small number had no recollection of growing things in school, the vast majority remembered growing plants from seeds at the elementary level. Seventy-five percent of these students, both before and after instruction in the cell, reported that the seeds planted in the dark did grow into plants, albeit not as well as those in the light (8E.2,
8E.3). Only a small number reported that the seeds planted in the dark grew but ultimately died (8E.5).

### TABLE 16

**Students' reports on experiments they carried out with plants in school**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>8E.1</td>
<td>I do not remember.</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>8E.2</td>
<td>The ones in the dark grew, but not very well.</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>8E.3</td>
<td>The ones in the dark grew, but they did not grow in an upward direction.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>8E.4</td>
<td>The ones in the dark stayed alive, but they did not grow. The sunshine is necessary for health.</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8E.5</td>
<td>The ones in the dark stayed alive a little while, but then they did die.</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

N = 20 20

4.3 **Alternative Conceptions of the Cell**

This section presents the results of this study as they relate to students' conceptions regarding the concept of the cell. Each subsection below addresses the alternative conceptions held by grade 10 students both prior to and after instruction in the cell. Each subsection contains a table representing the Composite Conceptual Inventory compiled for the appropriate constituent concept of the cell (see Table 3). Each table includes the alternative
conceptions, the conception identifiers, and the number of students identified as holding the alternative conceptions before "10b" and after "10a" instruction.

Each subsection also includes a brief summary of the results emphasizing the four key points outlined in section 4.2, but in this case as they relate to the concept of the cell. Two subsections also include the results of students' identifications of the specimen and photomicrograph used in the protocol. It is important to mention that the students observed and utilized specimens identical to the one presented in the protocol during their instruction. The students' observations and studies of cell division in their science classes were also based on drawings and slides of specimens similar to the one presented in the photomicrograph of the protocol. This was confirmed by the teachers giving the instruction in the four schools used for this phase of the study.

4.3.1 The Cell as the Basic Structure of Organisms

Conceptions of the cell as the basic structure of organisms were investigated with respect to three areas:

2. Cell identification and the relation of cells to growth.
3. The interaction of cells with body functions.

Of the 6 alternative conceptions identified from the students' Individual Conceptual Inventories regarding cell
differentiation, 4 were identified in more than 1 ICI (Table 12). Fifty percent of the sample both before and after instruction recognized that a person starts as a fertilized egg, but did not know how the parts originated (6A.1). Nine of the 20 students were found to have alternative conceptions prior to instruction.

**TABLE 17**

*Students' alternative conceptions of differentiation*

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A.1</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>The person starts as a fertilized egg. I do not know how all the different parts originate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A.2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>The organism starts as an egg with a group of cells for parts already there when it is created. These cells come together to form tissues and these tissues then come together to form organs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A.3</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>The egg is really a little ball. The different parts develop and get bigger. All the parts grow as you do. When you are concieved you have the cells for all your major parts.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A.4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>A baby develops in the womb from a fertilized egg through the division of cells. The process is mitosis and I do not know where the different parts of the body come from.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>In meiosis genes are randomized. The fertilized egg is a cell. The nucleus of the zygote divides with minor changes somehow. The chromosomes have the...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 17 (continued)

Students' alternative conceptions of differentiation

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A.5</td>
<td>...information for all the parts. This is by mitosis and the definition that it is the development of identical daughter cells is not correct.</td>
<td></td>
</tr>
<tr>
<td>6A.6</td>
<td>The parts are developed to meet its requirements through evolutionary development. Genes stimulated by DNA cause the different parts to form. There are sets of different cells in the embryo which make other different cells by genes. Cells will divide or die in areas depending on what is needed.</td>
<td></td>
</tr>
</tbody>
</table>

N = 20

The students' conceptions were classified into 3 general categories:

1. The different parts of a person originate from cells already present when the person is conceived (6A.2, 6A.3).

2. The different cells originate by cells going through mitosis but I do not know how differences in cells arise (6A.4).

3. The different parts of an organism originate from cells going through mitosis and being changed in some manner (6A.5, 6A.6).

All but 1 of the ICIs prior to instruction were found to fall into category 1. After instruction, the ICIs
classified as category 2 increased from 0 to 4, however those in category 3 increased only from 1 to 2. Only 2 students after instruction could be said to hold a conception of differentiation containing elements of a scientific conception, and both of these students suggested that the formal definition of mitosis might be incorrect.

The concept of differentiation in its complete form, including the central notion that during cell division it is the DNA that remains unchanged while the morphology and physiology of the cell may change, was not found in any of the ICIs. This concept was not introduced or discussed during instruction.

Twelve alternative conceptions of the cell's relation to growth were identified (Table 18). Of these, 7 were identified in more than one ICI. Two of these conceptions included only the identification of the specimen. Four ICIs reflected no conceptions in this area, 3 of which were prior to instruction.

TABLE 18

Students' identification of cells through the microscope and their alternative conceptions of the cell's relation to growth

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6B.1 I do not know.</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>6B.2 The specimen is a cell of some sort. I do not know where they come from.</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10b</td>
<td>10a</td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>6B.3</td>
<td>The specimen is a plant cell because it has a rigid shape. I do not know how it leads to growth.</td>
<td>0</td>
</tr>
<tr>
<td>6B.4</td>
<td>The specimen is a blood cell. Most living organisms have cells. Trees do not have cells. All of human cells are in the blood. The nutrients are delivered by these cells to the heart and kidney and they get bigger.</td>
<td>1</td>
</tr>
<tr>
<td>6B.5</td>
<td>The pointer is pointing at a little pink dot. It is a cell. The cell in animals divides to make you grow. As you get older the cells stop dividing. Plants just fill up.</td>
<td>2</td>
</tr>
<tr>
<td>6B.6</td>
<td>The specimen is a cell. If there were a mass of them increasing in size, the organism would grow.</td>
<td>2</td>
</tr>
<tr>
<td>6B.7</td>
<td>The specimen is an animal cell. All parts of animals have cells. Trees have only a few cells in the leaves. The trunk and the rest are just made out of molecules. The nutrients delivered to animal cells allow them the split, this makes the parts bigger.</td>
<td>0</td>
</tr>
<tr>
<td>6B.8</td>
<td>The specimen is a cell. The cell divides into more cells and the parts get bigger.</td>
<td>4</td>
</tr>
</tbody>
</table>
TABLE 18 (continued)

Students' identification of cells through the microscope and their alternative conceptions of the cell's relation to growth

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6B.9</td>
<td>The specimen is a cell, I am not sure what type. Cells are made by division in an organism constantly. If they are made faster than they die, you grow, if its the same, you stay the same, and if they die faster, you die.</td>
<td>0</td>
</tr>
<tr>
<td>6B.10</td>
<td>The specimen is a blood cell, it is red. It divides to form new cells.</td>
<td>1</td>
</tr>
<tr>
<td>6B.11</td>
<td>This is a plant cell because it seems in line. Everything is made of cells. The cells are growing, they are making more.</td>
<td>0</td>
</tr>
<tr>
<td>6B.12</td>
<td>The specimen is a plant cell because it has a rigid shape and the cells around it are very similar. Cells divide and you get bigger.</td>
<td>1</td>
</tr>
<tr>
<td>6B.13</td>
<td>The specimen is a plant cell because it has a cell wall and green chloroplasts. It looks like an onion cell. The cells divide and that is how you get growth.</td>
<td>1</td>
</tr>
</tbody>
</table>

N = 20 20

Students' alternative conceptions of the relationship between cells and growth were grouped into 4 broad categories:

1. Cells deliver nutrients to the body (6B.4).
2. Growth in animals is caused by cells dividing while
growth in plants is caused by cells filling up (6B.5).

3. Cells increase in size causing growth (6B.6).

4. Cells divide causing growth (6B.7 to 6B.13).

Seven ICIs prior to instruction were found to fall into category 4. Sixteen ICIs, or 80 percent of the sample, were classified in this category after instruction.

The division of cells was the key idea in these conceptions. The conception of the cell's involvement in growth did not include the replication of genetic material prior to division and the growth in size of the daughter cells after division. Only 1 ICI was found to contain a notion as to why an organism does not continue to grow in size as a result of continued cell division, namely, that cells constantly die and are replaced (6B.9). As in the previous section, conceptions regarding the appearance of different types of cells were not found.

The responses in Table 12 also provided information regarding the students' identification of the specimen. These identifications were organized into 5 categories:

1. The specimen is a cell (6B.2, 6B.5, 6B.6, 6B.8, 6B.9).

2. The specimen is a blood cell (6B.4, 6B.10).

3. The specimen is an animal cell (6B.7).

4. The specimen is a plant cell because of its shape (6B.3, 6B.11, 6B.12).

5. The specimen is a plant cell because it is green in colour due to chloroplasts (6B.13).
Thirteen of the 20 conceptions expressed prior to instruction fell into category 1 as did 8 conceptions after instruction. Eight ICIs after instruction were classified in category 4 while 2 were classified in category 5, the latter citing cell organelles as evidence for their identification. Fifty percent of the students identified the specimen which they had observed, drawn, and studied during instruction.

Table 19 presents the students' conceptions of cells' interactions with body functions. Six alternative conceptions were identified of which 5 were found in more than one ICI. Six students before instruction and 2 after stated they had no ideas in this area.

**TABLE 19**

*Students' alternative conceptions of cells' interaction with body functions*

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6C.1 I do not know.</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>6C.2 Cells are not involved in moving objects. That is a direct command from brain to muscle. I do not know the form the command takes. When cell wears out, the organism dies.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6C.3 Cells are involved in brain and muscle but I do not know how.</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>6C.4 The brain cells are responsible for thought but muscles control movement. When a person ages, cell reproduction slows down, and the old cells die, so does the person.</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6C.5 Your body communicates through the nucleus of cells.</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
TABLE 19 (continued)

Students' alternative conceptions of cells' interaction with body functions

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>6C.6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Your brain controls all of your body parts. Nerves carry messages in the form of electrical messages traveling through live cells. Your cells die and are not replaced when you get older, the parts shrink and eventually something breaks down.</td>
<td></td>
</tr>
<tr>
<td>6C.7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Nerve cells are responsible for sending all electronic communications between parts of the body.</td>
<td></td>
</tr>
</tbody>
</table>

\[ N = \]
20     20

The conceptions were classified into 3 categories:

1. Cells are not involved in body functions (6C.2).
2. Cells are involved in body functions (6C.3 to 6C.5).
3. Nerve cells are involved in all body functions and carry messages (6C.6 and 6C.7).

Eleven students prior to instruction and 9 after instruction held conceptions that were classified in category 2. Two students prior to instruction and 7 after held the conception that were classified in category 3. More than 65 percent of the sample was unclear on how cells were involved in body functions, after instruction. Nerve cells were the only type of specialized cell mentioned in this context.
4.3.2 The Structure and Function of the Cell

Students' conceptions regarding the structure and function of the cell were examined with respect to 3 major areas:

1. The identification of cell reproduction and its relation to growth.
2. Cell control and metabolism.
3. The concepts of mitosis and meiosis.

Eleven alternative conceptions were identified with respect to the identification of cell reproduction and its relation to growth (Table 20). Nine of these were identified in more than one ICI. Only 3 ICIs, all prior to instruction, were found not to contain conceptions.

TABLE 20

<table>
<thead>
<tr>
<th>Alternative Conception</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>7A.1 I do not know.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>7A.2 The object in the photo is part of a living thing.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>7A.3 The object in the photo is a blood cell. There is nothing in the photo that has anything to do with growth.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7A.4 The objects in the photo are cells from different organisms. The photo shows nothing to do with growth.</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 20 (continued)

Students' identification of the cell and mitosis in a photomicrograph and their alternative conceptions of the cell's relation to growth

| 7A.5 | The objects in the photo are different kinds of cells from the same organism. The photo does not show anything related to growth. | 7 | 1 |
| 7A.6 | The objects in the photo are plant cells because of their rigid shape. The nucleus is dark, the red are chloroplasts and I do not know what the blue green is. There is nothing to do with growth going on in the photo. | 0 | 2 |
| 7A.7 | The objects in the photo are cells from different organisms. Some are reproducing. Cells do not get bigger, they reproduce. That is where the food goes. | 1 | 0 |
| 7A.8 | The objects in the photo are dividing cells and are also different cells from the same animal, maybe blood and skin. | 1 | 6 |
| 7A.9 | The objects in the photo are different kinds of human cells. The nucleus is blue and the thick edge of the blue is the cell membrane. The green stuff separates the cells. The cells in contact with the blood get nutrients which make the chromosomes split. Two new cells form around the chromosomes. If there are not enough nutrients the cell will not split. | 0 | 1 |
Students' identification of the cell and mitosis in a photomicrograph and their alternative conceptions of the cell's relation to growth

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>7A.10 The objects in the photo are plant cells because of their rigid shape. Cell division is going on. The red dot is the nucleus.</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>7A.11 The objects in the photo are actively dividing plant cells, going through mitosis. I can not remember the names of the stages.</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7A.12 The objects in the photo are actively dividing plant cells. Some are dividing and in some the chromosomes are organising to divide. The first stage is arranging the chromosomes, preparing to split, spindle fiber pulls the nucleus apart, the cell wall grows in and 2 new cells have formed.</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>N =</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Alternative conceptions related to the relationship between the process occurring in the photomicrograph (mitosis in onion root tip cells) and its relationship to growth were classified into 6 categories:

1. Nothing related to growth is occurring in the photomicrograph (7A.2, 7A.3, 7A.6).

2. The photomicrograph shows cells from different organisms (7A.4).

3. The photomicrograph shows cells from different
organisms dividing (7A.7).

4. The photomicrograph shows different kinds of cells from the same organism (7A.5).

5. The photomicrograph shows different kinds of cells from the same organism dividing (7A.8, 7A.9).

6. The photomicrograph shows plant cells undergoing cell division (7A.10 to 7A.12).

Prior to instruction, 4 ICIs fell into category 1 and 7 ICIs fell into category 4. After instruction 7 ICIs fell in category 5 and 9 in category 6. Better than 75 percent of the sample recognised cell division in the photomicrograph after instruction. Less than 50 percent (9/20) held the conception that it was cell division in plant cells. The actual stages of mitosis visible in the photomicrograph and studied during instruction were mentioned by only 2 students.

None of the conceptions contained the concept of the replication of genetic material prior to division or the idea that cells increase in size after division.

The conceptions identified in Table 20 also provide information on how students identified the specimen in the photomicrograph. These identifications were grouped into 4 general categories:

1. The photomicrograph is of a living object (7A.2).
2. The photomicrograph is of an organism's cells (7A.4, 7A.5, 7A.7).
3. The photomicrograph is of an animal's cells (7A.3, 7A.8, 7A.9).

4. The photomicrograph is of a plant's cells because of their shape (7A.6, 7A.10, 7A.11, 7A.12).

Twelve conceptions prior to instruction and 9 after instruction fell into categories 2 and 3. Two conceptions prior to instruction and 11 conceptions after instruction fell into category 4. As in section 4.3.1, roughly 50 percent of the students identified the photomicrograph as being of the plant cells they had observed and studied during instruction.

Table 21 presents the students' conceptions of how the cell is controlled. Eight alternative conceptions were identified of which 7 were found in more than one ICI. Twelve students prior to instruction and 4 after stated that they had no conceptions in this area.

TABLE 21

<table>
<thead>
<tr>
<th>Students' alternative conceptions of cell control and metabolism</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>7B.1 I do not know.</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>7B.2 Parts of the cell are for different things.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7B.3 Your brain coordinates cells and tells them when to divide. You die when your cells wear out.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>7B.4 A cell has a brain. Cells take in nutrients and get rid of wastes. I do not know how they divide.</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 21 (continued)

**Students' alternative conceptions of cell control and metabolism**

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>7B.5</td>
<td>The nucleus controls how the cell works.</td>
<td>1</td>
</tr>
<tr>
<td>7B.6</td>
<td>The brain of the cell is the nucleus. A cell absorbs material and the amount controls dividing but I do not know how.</td>
<td>0</td>
</tr>
<tr>
<td>7B.7</td>
<td>The nucleus controls the cell. The cell membrane takes in the nutrients from the blood. The material around the cell wall consumes it. The material near the nucleus does not get as much. If the outside gets too big the nucleus gets no food so it splits.</td>
<td>0</td>
</tr>
<tr>
<td>7B.8</td>
<td>The chromosomes control the cell, tell it when to divide and so on.</td>
<td>0</td>
</tr>
<tr>
<td>7B.9</td>
<td>Both the DNA in the nucleus and hormones control how cells work and divide.</td>
<td>1</td>
</tr>
</tbody>
</table>

N = 20 20

The conceptions expressed were classified into 4 categories:

1. The person's brain controls cells (7B.3).
2. The cell has a nucleus (or brain) which controls it (7B.4, 7B.5).
3. The cell's chromosomes or genes and hormones control it (7B.8, 7B.9).
4. The amount of material absorbed by the cell controls
its division (7B.6, 7B.7).

After instruction, 4 ICIs were identified in category 2 and 8 in category 4.

Table 22 presents students' alternative conceptions of the meaning of the terms mitosis and meiosis. Of the 15 alternative conceptions identified, only 5 were identified in more than 1 ICI. The response with respect to this area of the cell was found to be the most similar prior to instruction and the most individualistic after instruction.

| Table 22 |
| Students' alternative conceptions of mitosis and meiosis |

<table>
<thead>
<tr>
<th></th>
<th>10B</th>
<th>10A</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C.1</td>
<td>I do not know.</td>
<td>20</td>
</tr>
<tr>
<td>7C.2</td>
<td>In meiosis living cells produce new ones. In mitosis an egg and a sperm meet to produce a new organism.</td>
<td>0</td>
</tr>
<tr>
<td>7C.3</td>
<td>Meiosis occurs in animals and involves the cell and nucleus dividing in two. Mitosis occurs in plants and involves a cell dividing into four.</td>
<td>0</td>
</tr>
<tr>
<td>7C.4</td>
<td>Mitosis is the growth of plants and shows how some of the cells in the leaf reproduce. Meiosis is reproduction in humans. There is no meiosis in plants and no mitosis in humans.</td>
<td>0</td>
</tr>
<tr>
<td>7C.5</td>
<td>Mitosis is the splitting of cells in plants and meiosis is the splitting of cells in humans. Both go through stages.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Students' alternative conceptions of mitosis and meiosis</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>7C.6</td>
<td>Mitosis is a stage in cell division. That's all I remember.</td>
<td></td>
</tr>
<tr>
<td>7C.7</td>
<td>Mitosis is the division of cells. It includes stages like interphase, metaphase, telophase and so on. I do not remember what meiosis is.</td>
<td></td>
</tr>
<tr>
<td>7C.8</td>
<td>Mitosis is the development of two identical daughter cells from one parent cell. Meiosis is the development of one daughter cell from two parent cells.</td>
<td></td>
</tr>
<tr>
<td>7C.9</td>
<td>Mitosis is the division of cells into identical copies and it occurs in both plants and animals. In meiosis the fertilized egg makes copies with both parent's chromosomes and then divides.</td>
<td></td>
</tr>
<tr>
<td>7C.10</td>
<td>Mitosis and meiosis are both reproducing cells. One is sexual and the other asexual, I do not remember which. They both had stages.</td>
<td></td>
</tr>
<tr>
<td>7C.11</td>
<td>Mitosis is making cells through asexual reproduction and meiosis is dividing cells through sexual reproduction.</td>
<td></td>
</tr>
<tr>
<td>7C.12</td>
<td>Mitosis has only one parent cell, it is cell division in plants. Meiosis has two parent cells, it is the division of the cells that make the fertilized egg.</td>
<td></td>
</tr>
</tbody>
</table>
### Students' alternative conceptions of mitosis and meiosis

<table>
<thead>
<tr>
<th>Concept</th>
<th>Category</th>
<th>10B</th>
<th>10A</th>
</tr>
</thead>
<tbody>
<tr>
<td>7C.13</td>
<td>Meiosis involves the cell dividing into four and mitosis involves the cell dividing into two.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7C.14</td>
<td>Mitosis produces two identical daughter cells and chromosomes after division. Meiosis produces cells after division which are not the same.</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7C.15</td>
<td>Both are cell division. Mitosis starts out as one and ends out as two. Meiosis will get you different ones and then those two split into more. Meiosis goes through mitosis twice, more cells come out of it.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7C.16</td>
<td>Mitosis is the process of dividing of cells into new cells, excepting the gametes. In mitosis you get two diploid cells from the parent that are identical. Meiosis is the division of sex cells, first you get 4 cells with random chromosomes. The chromosomes double in the first cells and it divides twice to give you 4 haploid cells.</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Prior to instruction no student expressed a conception regarding the meaning of these concepts (7C1). After instruction, all students expressed conceptions regarding these concepts which were grouped into 7 categories:

1. One of the two (mitosis or meiosis) occurs in animals and the other one in plants (7C.4, 7C.5).
2. One of the two produces more cells than the other (7C.13, 7C.15).

3. One of the two occurs in animals and the other in plants and one of the two produces more cells than the other (7C.3).

4. Mitosis is the division of cells, meiosis is something else (7C.6, 7C.7, 7C.8, 7C.9, 7C.14).

5. One of the two is asexual reproduction and the other is sexual reproduction (7C.2, 7C.10, 7C.11, 7C.12).

6. Basically a scientific conception, as expressed by 2 students in 7C.16.

Some of the elements of a scientific conception of mitosis were identified in 9 ICIs after instruction as found in conceptions 7C.7, 7C.8, 7C.9, 7C.14, 7C.15, and 7C.16. Roughly scientific conceptions of both mitosis and meiosis where identified in 2 ICIs (10 percent of the sample) after instruction, as found in conception 7C.16.

The qualifiers "basic" and "roughly" are used above because none of the conceptions included the notions of DNA replication before division, cell growth after division, and differentiation of cells. The first two were studied by the students during instruction. The stages representing the two processes were also studied in the classroom. Only two students were able to outline these stages for mitosis (7C.7) and none were able to provide details about the stages in meiosis.
4.4 General Discussion of Alternative Conceptions

4.4.1 Introduction

This section summarizes the results presented above and relates them directly to the research questions presented in Chapter 1. The validity of the assumptions discussed in Chapter 1 regarding students' conceptions of growth and the cell will also be considered in light of these results.

The results clearly suggest that the students in this sample held a variety of alternative conceptions concerning various aspects of biological growth and the cell. With respect to the concept of growth, 138 different alternative conceptions were identified, 78.3 percent of which were found to be held by more than one student. For the cell, 77 alternative conceptions were identified of which 68.8 percent were identified in more than one student. This variability in conceptions was identified at all grade levels and both before and after instruction.

It is also clear from the results presented in this chapter that the students in this sample formulated alternative conceptions regarding many of the constituent concepts of growth and the cell prior to encountering them in the formal learning situations. All the students interviewed prior to instruction in growth were found to hold some conceptions regarding the concept, while 85 percent of the students at the grade 10 level held some conceptions regarding the cell prior to instruction in that
The nature of the sample does not allow specific statistical claims to be made on the basis of the results, that is, generalizing specific results from this sample to the entire population of students in the Province. The data does, however, allow a cautious generalization to be made regarding the first of the assumptions made by the curriculum regarding student knowledge discussed in Chapter One. The assumption that "the student has no personal conceptions of the structure and growth of living things prior to instruction" is not supported by these results.

Furthermore, the assumption that "the student will incorporate the conceptions presented in the materials into his cognitive structure without alteration or modification" also appears to be untenable based on the wide variety of alternative conceptions identified at the various grade levels. The remainder of this section will identify in a more general sense the conceptions held by students with respect to the major constituent concepts of growth and the cell.

4.4.2 The Concept of Growth

Students' conceptions with respect to the parameters of growth suggest that a majority of students viewed growth from a macroscopic, descriptive level. The inclusion of life or cells as being necessary for the growth of organisms was
identified in only a minority of students at all levels. These results can be expected if knowledge acquisition is viewed in terms of the learner being engaged in the active process of making sense of a wide variety of experiences related to the phenomenon in question. For example, all students will have experienced directly in some way the physical increase in size and the change in characteristics associated with growth. The concepts of life or the cell, however, are not accessible through direct experience and will therefore have to be incorporated into their knowledge base as a result of other indirect experiences such as television or books. These other indirect experiences usually require some type of linguistic competence in order to assimilate verbal information about the phenomena.

Alternative conceptions related to the acquisition of requirements for growth supports this suggestion. Water was seen as the primary requirement necessary for growth in plants by most students. This confirms the findings of two recent studies which also investigated aspects of growth (Lawson, 1988; Russell and Watt, 1989). In a number of cases a second alternative conception commonly found in previous studies (Smith and Lott, 1983; Wandersee, 1983; Smith and Anderson, 1984) was also identified, namely that soil is the food for plants. Sunlight was seen as a secondary requirement at best. Conceptions including a clear notion of the role of gases were not identified at any level. Water is
a requirement that can be understood to be necessary for growth from basic experience. The necessity of sunlight, on the other hand, is knowledge more likely dependent on formal instruction.

Photosynthesis is a concept taught at the intermediate and secondary levels which requires the student to hold a conception in which gases such as oxygen and carbon dioxide are viewed as important requirements for growth. If gases are not components of the students' conceptions, it is very unlikely that they will actively adopt photosynthesis as an explanation for the phenomena of plant growth. This conjecture is supported by the results of this study. A clear scientific conception of photosynthesis was identified in only 4 of the 90 individual conceptual inventories.

Students conceptions with respect to the requirements for growth in animals were similar to those in plants in that the concrete necessities of water and food are almost universal while the notion of the necessity of oxygen is virtually non-existent. The consequences of this alternative view may have the same impact on students' understanding of respiration in animals as for their understanding of photosynthesis in plants.

Some evidence for this suggestion is provided by examining students' conceptions regarding "the use of the requirements necessary for growth". The majority of students either answered "I do not know" or suggested a "push-out"
model, that is, the requirements simply enter the organism and push out on the inside of the trunk or leaf surface in plants. The notion that the materials are somehow changed when they enter the plant was found in only a small minority of the elementary students and approximately 50 percent of the grade 10 students, even after instruction in the cell. If students' conceptions do not include this notion of change one would predict that very few would construct a scientific conception of growth, for example, "photosynthesis supplies the food necessary for cells to divide which results in the growth of the plant". Only 6 ICIs were found to contain this conception and none of these were found to include gases as a component of photosynthesis.

In animals the results are somewhat different. Changes in the consumed materials was seen as important to growth by roughly 25 percent of the students at all of the 3 elementary levels. At the secondary level, however, some form of change in the materials causing growth was suggested by 75 percent of the students prior to instruction. Again, first hand experience may play a large part in the formation of this conception. It is important to note, however, that 60 percent of the grade 10 students still invoked the push-out model, with or without the notion of change. Fifteen percent stated that they did not know, while the remaining 25 percent made specific reference to the nutrients
supplying cells with energy and the cells dividing. Oxygen was not seen by these students as playing any part in the process.

The push-out model, identified in both plants and animals, is a simple, experience based model to which photosynthesis and cell division are not necessary components. It is interesting that a number of students at the elementary level answered in the affirmative a follow-up question in the protocol asking if growth in living things was like the growth of a balloon.

Students conceptions regarding the instigation of growth in plants again included water as the primary prerequisite. At the elementary level the conceptions were more varied than at the secondary level. Over 60 percent of the grade 10 students held a conception that included water as the only requirement necessary for growth. This conception is clearly consistent with experience in the home with plants. No students at any level included any extensive references to the outdoor garden or forest environment in their conceptions.

On the basis of previous classroom experience (Table 15), one might expect the students' conceptions to include some reference to the necessity of light or the sun. When the grade 10 students were asked if they could recall the results of any experiments they carried out with respect to growth in plants during their schooling, 17 of the 20
students related the "controlled conditions" experiment with plants (Table 16). Fifteen of the students stated that while the plants placed in the dark did not grow very well, they did in fact continue to grow. These students were from 4 different grade 10 classes and a greater number of different elementary classes.

The students' observations may have been correct. The problem often lies in not allowing the experiment enough time to reach its conclusion, that is, allowing sufficient time for the plants in the dark to die. This possibility was actually documented in a classroom case study (Smith and Anderson, 1984) and again identified by Lawson (1988). The majority of students in this study appear to have drawn the conclusion from their experimental observations that water is the primary requirement for plant growth and light plays only a secondary role.

The results suggest that the students' conception of the seed may also be a very simple one. It is interesting to note that 70 percent of the grade 10 students described a seed as "non-living", even after instruction (Table 11). This basic difficulty with the concept of life was also encountered by Tamir, Gal-Choppin, and Nussinovitz (1981). Of the 83 students in their sample aged 10-15, 19 percent were found to hold that living things could originate from non-living objects. Of the total sample in their study of 394 students aged 8-15, 39 percent held a conception of
seeds as being non-living.

There is evidence to suggest that this problem may contribute to alternative conceptions even at the university level. Brumby (1982) reported that only a small minority of students in first year Biology classes in both British and Australian universities included self replication or DNA in their explanations of life. This problem may have roots in students' conceptions of the structure of the body as well. Stavy, Eisen, and Yaakobi (1985) reported that the majority of 33 students aged 13-15 were startled upon confronting the fact in instruction that the human body was made of chemicals. If this basic conception is not present in the student, it is likely that it would be extremely difficult to have a student accept the complex conceptions related to DNA, photosynthesis, or any aspects of biochemistry.

The majority of the primary students in this sample held a conception of the instigation of human growth as beginning with a fully formed baby which grows as it is supplied with food from the mother. Six of 18 students at the grade 5 level and 6 of 10 students at the grade 7 level held a conception which included a cell in the mother growing into a baby. Lawson (1988) identified this conception in 1 of the 3 primary students he interviewed in his study. In this study, only 1 student at the grade 7 level and 55 percent of the students at the grade 10 level after instruction held a scientific conception of
fertilization.

The majority of students' conceptions with respect to the cessation of growth in plants include a notion of a limit to upward growth caused by a variety of factors. Russell and Watt (1989) also found that the majority of the 62 students in their primary sample held a conception in which plants stopped growing at a certain point. The conception that plants stop growing when their cells stop dividing was held by 35 percent of the grade 10s after instruction.

For a variety of reasons, animals are also seen as being limited in their ability to grow. As in the case with plants, 50 percent of the grade 10s held that growth stopped when cells stopped dividing. In both plants and animals, only a minority of students held a conception in which growth stopped only upon the death of the organism.

4.4.3 The Cell

The results discussed above suggest that the students in this sample did not have a scientific conception of the instigation of growth in plants or animals. Central to this conception is an understanding that development does not only occur through the division and growth of cells but also through their differentiation, that is, the development of different kinds of cells with different functions. It was argued in Chapter 1 that curricula implicitly make the assumption that students will hold a conception of cell
differentiation. This argument was based on the observation that British Columbia science curricula up to the grade 11 level do not treat this concept.

Students' conceptions of differentiation as they were identified in this study do not support this assumption. More than 50 percent of the students stated that they did not know where the different parts of organisms originated. A further 40 percent prior to instruction held an alternative conception that saw the different parts of a person being already present at biological conception, an idea bearing similarities to the preformation theory of the early eighteenth century. These results support the findings of a number of authors (Schaefer, 1979; Okeke and Wood-Robinson, 1981; Hackling and Treagust, 1982) that suggest that students have no prior conceptions of differentiation because it is unlikely they have an opportunity to experience any aspects of the phenomenon. Changes identified in these conceptions after instruction will be discussed in Chapter 5.

These results suggest that students do not have a conception of growth which includes differentiation when they come to the instructional situation. It is therefore important that differentiation be explicitly presented during instruction if the aim is to provide students with the opportunity to construct a scientific conception of
growth. Failure to provide such an opportunity has been referred to by Fisher (1984) as an "error of omission" in curriculum. The result of such an "error" may not only be the formation of alternative conceptions after instruction. It also results in the student not being given the opportunity to generate the necessary relationships between this concept and others. This will result in further difficulties which become progressively more difficult to elucidate.

Students' conceptions of the cell's relationship to growth prior to instruction were mixed, with 40 percent of the sample stating they did not know. Another 35 percent of the students held a conception in which cell division was seen as being responsible for growth. It is important to note however, that while this conception might be considered as a scientific conception at the general level, it did not include a number of factors important at a more specific level. For example, the notion of the constant death and replacement of cells was not mentioned before instruction nor was the growth of individual cells after replication mentioned by the students. The inclusion of DNA in conceptions was also conspicuously absent. Okeke and Wood-Robinson (1980) concluded from their study of the learning difficulties in biology of 120 Nigerian students aged 16-18 that "a large number of pupils exhibited total confusion
between cell division, enlargement, and cell differentiation". Brumby's (1981, 1982) studies, discussed in Chapter 2, reported student difficulties with DNA at the university level.

While it might be argued that the conception of growth as cell division is sufficient at this level, it is important to recognize that holding this conception may lead students to believe that individuals stop growing because their cells stop dividing (Table 13 and Table 14). Cell division, growth, and death, are all necessary to a scientific conception of growth.

In discussing the relationship of cells to growth, no students mentioned the notion of the development of different kinds of cells. This is consistent with their conceptions directly related to differentiation (Table 18).

Students' conceptions regarding the relationship of the cell to body functions were unclear. Sixty percent held a conception that cells were involved in body functions but could not suggest an example. The one student that did suggest an example used the nerve cell. There is a lack of reference to the existence of different kinds of cells which may in part be explained by the lack of a conception of how different cells are produced during development.

The majority of grade 10 students in the sample (60%) had no conception of how the cell was controlled or how it
operated. Four of the 20 students held that each cell had a brain or nucleus which controlled it, while 1 student held that the chromosomes directly controlled the cell's activities. Students' conceptions in this area were not very developed. The same was true regarding the students' conceptions of mitosis and meiosis. Prior to instruction, all the students in the sample reported that they did not know what these concepts meant.

Eighty-five percent of the students prior to instruction were able to identify the specimen under the microscope as a cell. Of the 20 students comprising the sample, only 2 were able to identify it as a plant cell. The results were much the same for the photomicrograph; while 14 of the 20 students were able to identify the objects as cells, only 2 were able to identify them as plant cells.

Prior to instruction, only 20 percent of the grade 10 students in the sample suggested that the cells in the photomicrograph were undergoing cell division. While 7 of the students held a conception that cell division was responsible for growth, only 4 of them could identify the process in the photomicrograph.

The findings discussed above suggest that the majority of students in the sample upon coming to instruction in grade 10 had some notion of the cell being a basic component
of living things. It appears, however, that the cell only becomes important when the student is discussing biology at the microscopic level. When asked in the interview protocol about the general parameters of growth, the cell was not mentioned at all.
CHAPTER FIVE

CHANGE IN STUDENTS' CONCEPTIONS OF GROWTH AND THE CELL

5.0 Introduction

This chapter presents the results relating to the third and fourth research questions posed in this study, namely:

3. Do the grade 3 students' conceptions of growth change after instruction in science?

4. Do the grade 10 students' conceptions of growth and the cell change after instruction in science?

The chapter is divided into four major sections, not including this introduction. The first section outlines the method of data analysis. The results related to changes in frequency of conceptions of growth at both the elementary and secondary level are presented in section 2, those related to changes in the frequency of conceptions of the cell at the secondary level are presented in section 3. The final section of the chapter presents a discussion of the results and how they relate to research questions 3 and 4.
5.1 Data Analysis

In order to analyse the change in students' conceptions after instruction in growth at the elementary level and the cell at the secondary level, the number of students holding conceptions in each of the broad categories identified in Chapter 4 was tabulated. This level of analysis, while losing some of the specificity and individuality of the composite conceptual inventories, allows a more general analysis of changes in what appear to be the more predominant conceptions held by the sample. It is this level that will be of most use to the teacher attempting to address learning difficulties in the classroom and to the curriculum developer attempting to identify specific objectives for instruction.

At the elementary level, 11 students were interviewed using the growth protocol prior to instruction. These 11 students were interviewed again three weeks later after completing the "Community and Living Things" unit which dealt with, amongst other things, growth in plants. Students were exposed to scientific concepts related to most of the questions posed by the protocol during instruction, although at a basic level. Students also grew pea plants under various conditions during the unit. Eight of these 11 students were interviewed again 2 years later when they were in grade 5.

The number of these students holding conceptions
falling into each of the major categories identified for each of the constituent concepts of growth was tabulated for each of the interview periods.

Twenty students at the grade 10 level were interviewed using the cell protocol both before and after a unit of instruction on the cell. During instruction, the students were exposed to scientific concepts related to the majority of questions posed in the protocol. These included basic cell structure, cell division and the stages of mitosis, forms of reproduction and meiosis. The students also made extensive observations of plant cells and mitosis in onion root tip cells through the use of the microscope. It is important to note that the students were not exposed to the concept of differentiation nor were specific links drawn between the general concept of growth and the more specific concepts of cell and mitosis.

The number of grade 10 students holding conceptions falling into each of the major categories identified for each of the constituent concepts of growth and the cell was tabulated for each of the two interview periods.

These results are organized into the tables presented in this chapter. As in the previous chapter, the grade 3 level prior to instruction in growth is indicated by "3b" in each table, the grade 3 level 3 weeks after instruction is indicated by "3a" and the 8 students interviewed 2 years later when they were in grade 5 is indicated by "5a". The
grade 10 level prior to instruction in the cell is indicated by "10b" and after instruction by "10a". The number of students identified in each level in each category is represented by a number.

With each table there is a short discussion which summarizes the results with reference to changes in the frequencies of conceptions identified in the categories from before to after instruction.

5.2 Changes in the Frequency of Students' Conceptions Related to the Concept of Growth

Students' conceptions related to the parameters of growth (Table 23) did not change to any great extent either at the elementary or secondary level. The majority of conceptions identified growth primarily as an increase in size with some students also including a change of appearance in their conceptions. While elementary instruction is aimed at linking growth in living things to life, only one of the 11 students was found to adopt this conception. This conception was again identified in this student at grade 5.

While no specific link between cell division and growth was presented explicitly during grade 10 instruction, it has been assumed that students would make this link. The results suggest that this assumption may not be correct for the majority of students. While 3 students changed to a
scientific conception of growth, 16 students held to their previous alternative conceptions which identified growth simply as an increase in size or a change in appearance.

TABLE 23

<table>
<thead>
<tr>
<th>Categories of conceptions related to the parameters of growth and the number of students identified in each category</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10a</th>
<th>10b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Growth is identified primarily as increasing in size.</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>2. Growth is identified as an increase in size but also a change in appearance.</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3. Being alive is the primary parameter of growth.</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. Having cells is the primary parameter of growth.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. Cell division is the microscopic explanation for growth at the macroscopic level.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>N =</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Students' conceptions regarding the sources and acquisition of requirements for growth at the elementary level showed some change after instruction (Table 24). The number of students holding the basic alternative conception decreased by 4 while the number expressing a notion of change in the materials increased by 4. At the grade 5 level, however, the notion of change was not identified in 3 students who were found to express it after instruction at the grade 3 level. At the grade 5 level, 7 of the 8 students held alternative conceptions in which soil and water were
seen as the food for the tree and light was considered only as a secondary requirement.

At the secondary level, no major changes were evident in the students' conceptions. Four of the 5 students who included sunlight and photosynthesis as important components of their conceptions prior to instruction held this conception after instruction.

For animals, all the elementary students and the majority of secondary students held conceptions which included water and food as the primary requirements for growth prior to instruction. The only change after instruction was noted in the grade 10 students, where 4 individuals adopted the more basic alternative conception which did not include a notion of change in the nature of materials required for growth.

TABLE 24
Categories of conceptions related to the sources and acquisition of requirements for growth in plants and animals and the number of students identified in each category

<table>
<thead>
<tr>
<th>Plants</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water and soil are the food of the tree and come in from the outside, move through the roots, and up into the branches and leaves.</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2. Water and soil are the food for the tree and come in from the outside, move through the roots, and up into the branches and leaves. Light has a secondary function.</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>
TABLE 24 (continued)

Categories of conceptions related to the sources and acquisition of requirements for growth in plants and animals and the number of students identified in each category

<table>
<thead>
<tr>
<th>Plants</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. The material that enters the tree is changed and this changed material is the food for the tree. The sun is involved in a general sense and enters through the leaves.</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>4. The material that enters the tree is all necessary for growth, but sunlight somehow involved with photosynthesis is the most important.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animals</th>
<th>11</th>
<th>11</th>
<th>8</th>
<th>12</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Food and water are the primary requirements for growth. These go from the mouth to the heart, esophagus, or stomach.</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>2. Food and water are the primary requirements for growth. These go from the mouth to the stomach, are then changed, and then go to the body.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Prior to instruction, 45 percent of the students at the elementary level and 40 percent of the students at the secondary level stated that they did not know how plants used the requirements needed for growth in order to develop and increase in size (Table 25). After instruction at the elementary level the frequency of this statement decreased
while the number of students holding a conception involving the push-out model increased to 45 percent. The frequency of conceptions including the idea of a change occurring in the materials increased to 18 percent. At the grade 5 level only 1 student stated he did not know, 4 still held the "push-out" model while 3 students evoked the notion that the materials changed when they entered the plant.

At the secondary level, there was not a great change in students' conceptions regarding the uses of requirements for growth after instruction. The 3 students holding the scientific conception involving cell division and photosynthesis before instruction continued to do so after instruction while 2 more students included photosynthesis in their conceptions and a further 2 included cell division after instruction.

Students' conceptions of the use of materials for growth in animals did not change appreciably at the elementary level after instruction. There was a marked change, however, at the secondary level. The number of students holding conceptions that fell into general category 4 (the scientific conception that in animals nutrients supply the cells with energy allowing the cells to divide, creating more cells, and thereby growth) increased from 5 (25%) before instruction to 14 (70%) after instruction.

It is interesting to note that during instruction the students were exposed primarily to plant cells and observed
cell division in plant cells, yet only 25 percent were found to hold conceptions of plant growth which involved cell
division. The unit of instruction on human reproduction in
which the students participated after the unit on the cell
may in part be responsible for the greater linking of cell
division to growth in animals.

TABLE 25

Categories of conceptions related to the uses of requirements for growth in plants and animals and the number of students identified in each category

<table>
<thead>
<tr>
<th>Plants</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>1. Materials, primarily water, go into the plant and push out on the parts causing them to expand or grow.</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2. Materials change into something else when they are in the plant and make it grow.</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3. Photosynthesis is responsible for growth in plants.</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4. Cell division is responsible for growth in plants.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>5. Photosynthesis supplies the food necessary for cells to divide which results in the growth of the plant.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>N =</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Animals

| i. I do not know. | 4  | 3  | 2  | 3   | 1   |
TABLE 25 (continued)

Categories of conceptions related to the uses of requirements for growth in plants and animals and the number of students identified in each category

<table>
<thead>
<tr>
<th>Animals</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Food and liquids go to the body</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>forcing it outwards and increasing its size.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. The materials upon entering the body</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>are changed into blood, which causes the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>muscles and/or the bones to grow,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stretching out the skin, or pushing out the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>parts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The nutrients in the blood</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>supply the cells which grow bigger or</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>somehow increase in number, causing the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bones to grow and the parts to get bigger.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. The nutrients supply the cells with</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>energy allowing the cells to divide, creating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>more cells, and thereby growth.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N = 11 11 8 20 20

Grade 3 students' conceptions regarding the instigation of growth in plants changed after instruction (Table 26). While the majority of these students held that only water or water and a seed were necessary to begin growth before instruction, 7 of the 11 students included the need for requirements other than water after instruction. This may reflect the emphasis put on the factors affecting the instigation of growth during instruction. At the grade 5 level, however, the 8 students are distributed evenly over
the 4 categories, with only 2 retaining the multiple needs conception.

At the grade 10 level, 60 percent of the students felt before instruction that only water and a seed were necessary for growth and 65 percent held the same conception after instruction. Six students before instruction suggested that germination was the result of a number of different factors while only 3 held this conception after instruction.

In animals, the majority of elementary students (8/11) held the notion that a person starts in the mother as a baby and is supplied with food which allows it to grow. After instruction this number fell to six, the other 2 students reported that they did not know. The six students were found to hold the same conception 2 years later in grade 5. No student at the elementary level suggested that a person starts as a result of the union of egg and sperm or that a human developed through cell division from a fertilized egg.

Eleven grade 10 students held conceptions in the general category of life starting as an egg and the egg growing as a result of food supplied by the mother. Surprisingly, after the instructional unit which included human reproduction, 45 percent of the students maintained this alternative conception. The other 55 percent included the egg being fertilized by a sperm in their conceptions. While 1 grade 10 student before instruction suggested that division of the zygote was responsible for subsequent
growth, this student did not include the cell as part of this conception.

**TABLE 26**

Categories of conceptions related to the instigation of growth in plants and animals and the number of students identified in each category

<table>
<thead>
<tr>
<th>Plants</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1. Plants start as seeds and need things not including water to grow.</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2. Plants start as parts cut off or fallen off of other plants. These get in the soil and grow.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. In order for plants to begin to grow, a seed need only be supplied with water.</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>4. In order for plants to begin to grow, a seed needs water and other requirements.</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>N =</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animals</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1. A person starts life as a baby in the mother and is supplied with food.</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2. A person starts life as an egg, food is supplied by the mother.</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>3. A person starts life as an egg fertilized by a sperm, food is then supplied by the mother.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>
TABLE 26 (continued)

Categories of conceptions related to the instigation of growth in plants and animals and the number of students identified in each category

Animals

<table>
<thead>
<tr>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

4. A person results from an egg being fertilized by a sperm, which then grows as a result of division nourished by nutrients from the mother.

N = 11 11 8 20 20

Table 27 presents the change in frequency of conceptions regarding the nature of the seed from before to after instruction at the grade 10 level. It is interesting to note that the number of "I do not know" responses decreased after instruction and that the majority of these students joined an existing 35 percent holding the alternative conception that seeds are non-living before they begin to grow. A total of 70 percent of the grade 10 sample after instruction held this conception. Three students, both before and after instruction, stated that seeds are alive when they are not growing.

TABLE 27

Categories of conceptions related to the nature of the seed in plants and the number of students identified in each category

<table>
<thead>
<tr>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

i. I do not know.
TABLE 27 (continued)

<table>
<thead>
<tr>
<th>Categories of conceptions related to the nature of the seed in plants and the number of students identified in each category</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seeds are non-living when they are not growing.</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>2. Seeds are dormant when they are not growing.</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3. Seeds are alive when they are not growing.</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

N = 20 20

The majority of students' conceptions regarding the cessation of growth in plants at all levels fell into category 1 (Table 28), that is, that plants stopped growing upward for a variety of reasons. A change occurred in the number of grade 10 students' conceptions identified in category 3 from before to after instruction. While only 1 suggested that plants stopped growing when their cells stopped dividing before instruction, this conception was expressed by 7 after instruction. Two more students after instruction invoked cell division in their conception of the cessation of growth in plants than invoked cell division in their conception of the use of requirements for growth in plants (Table 25). More importantly, this alternative conception suggests that students view cell division as continuing only until the organism is full grown and then stopping. Growth as including the continual death and
replacement of cells does not appear to be a conception held by many students even after instruction.

This suggestion is supported by the results as they relate to animals. The majority of students at the elementary level and prior to instruction at the grade 10 level held that animals stop growing for some reason but go on living. After instruction at the grade 10 level the number of students holding the same alternative conception as discussed above for plants, namely that animals stop growing when their cells stop dividing, had increased from 6 to 10. This group represents 50 percent of the grade 10 students and also 10 of the 14 students that used cell division in their conceptions of "the use of materials for growth" (Table 25).

TABLE 28

<table>
<thead>
<tr>
<th>Categories of conceptions related to the cessation of growth in plants and animals and the number of students identified in each category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
</tr>
<tr>
<td>i. I do not know.</td>
</tr>
<tr>
<td>1. Plants stop growing in an upwards direction for a variety of reasons.</td>
</tr>
<tr>
<td>2. Plants do not stop growing, they grow slowly.</td>
</tr>
<tr>
<td>3. Plants stop growing when cells stop dividing.</td>
</tr>
<tr>
<td>4. Plants stop growing when they or their cells die.</td>
</tr>
</tbody>
</table>
TABLE 28 (continued)

Categories of conceptions related to the
cessation of growth in plants and animals
and the number of students identified in
each category

<table>
<thead>
<tr>
<th>Plants</th>
<th>N =</th>
<th>3b</th>
<th>3a</th>
<th>5a</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 11</td>
<td></td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Animals

i. I do not know.  
1. Animals stop growing for some reason but go on living.  
2. Animals stop growing, and this is controlled by something in the animals. Animals then go on living.  
3. Animals stop growing when their cells stop dividing.  
4. Animals do not stop growing until they die.  
   
<table>
<thead>
<tr>
<th>Animals</th>
<th>I do not know.</th>
<th>1</th>
<th>1</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 Changes in the Frequency of Students' Conceptions Related to the Concept of the Cell

The results as they relate to the concept of differentiation (Table 29) suggest that students' conceptions regarding the concept have not changed substantially after instruction. Fifty percent of the students stated after instruction that they did not know where different cells in an organism came from. Four students were found to hold a new conception in which
mitosis is seen as being responsible for the production of cells but they still did not know how different cells arise. While 40 percent (8) of the students held a conception involving preformation before instruction, only 16 percent (4) were found to hold this alternative conception after instruction. Two students after instruction held a conception in which cells were seen as changing in some manner but they were unclear on how these changes occur.

TABLE 29

<table>
<thead>
<tr>
<th>Categories of conceptions related to differentiation and the number of students identified in each category</th>
</tr>
</thead>
<tbody>
<tr>
<td>10b</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>i. I do not know.</td>
</tr>
<tr>
<td>1. The different parts of a person originate from cells already present when the person is conceived.</td>
</tr>
<tr>
<td>2. The different cells originate by cells going through mitosis but I do not know how differences in cells arise.</td>
</tr>
<tr>
<td>3. The different parts of an organism originate from cells going through mitosis and being changed in some manner.</td>
</tr>
</tbody>
</table>

N = 20  20

A change in students' conceptions regarding the relation of the cell to growth was found to occur after instruction (Table 30). Seven of the 20 grade 10 students prior to instruction held a conception in which growth was
seen to result from cell division. The number of students identified as holding this conception increased to 16 students (80%) after instruction. It is important to recognize, however, that this conception did not include the concepts of cell replacement, individual cell growth after division, or replication of genetic material, the latter two of which were treated explicitly during instruction.

### TABLE 30

<table>
<thead>
<tr>
<th>Categories of conceptions of the cell's relation to growth and the number of students identified in each category</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
</tr>
<tr>
<td>1. Cells deliver nutrients to the body.</td>
</tr>
<tr>
<td>2. Growth in animals is caused by cells dividing while growth in plants is caused by cells filling up.</td>
</tr>
<tr>
<td>3. Cells increase in size causing growth.</td>
</tr>
<tr>
<td>4. Cells divide causing growth.</td>
</tr>
</tbody>
</table>

Students' conceptions of the interaction of cells with general body functions after instruction were limited in terms of their specificity. After instruction, 5 more students were identified in the category of conceptions which included nerve cells being involved in body functions through the sending of messages. Forty-five percent of the
students stated that cells are involved in body functions but they did not elaborate on how. One student held a conception which specifically included the interaction of nerve cells both before and after instruction.

**TABLE 31**

*Categories of conceptions of cells' interactions with body functions and the number of students identified in each category*

<table>
<thead>
<tr>
<th>Category</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1. Cells are not involved in body functions.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2. Cells are involved in body functions.</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>3. Nerve cells are involved in all body functions and carry messages.</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td><strong>N</strong></td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

A major change can be identified in students' ability to recognize cell division after instruction (Table 32). Prior to instruction 4 students recognized cell division in the photomicrograph while after instruction 16 of the 20 students (80%) recognized cell division in the photomicrograph. Of the 16 students, 9 were able to correctly identify the type of cell that was dividing. None of the students, however, related the cellular process to the growth of the roots of the onion plant during this part of the interview. This finding is surprising in view of the fact that 80 percent of the sample held conceptions of
growth as being the result of cell division when asked specifically about this relationship (Table 30). It is also important to remember that only 25 percent of the students held conceptions regarding the uses of requirements by plants that included cell division (Table 24). This suggests that while students were able to identify cell division in plants at the microscopic level, they were not able to link this conception with their macroscopic conceptions of growth in plants. One possible explanation for this finding is that this relationship is not made explicit during instruction.

TABLE 32

Categories of conceptions of the relation of the cell and mitosis to growth and the number of students identified in each category

<table>
<thead>
<tr>
<th></th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1. Nothing related to growth is occurring in the photomicrograph.</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>2. The photomicrograph shows cells from different organisms.</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3. The photomicrograph shows cells from different organisms dividing.</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4. The photomicrograph shows different kinds of cells from the same organism.</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>5. The photomicrograph shows different kinds of cells from the same organism dividing.</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>6. The photomicrograph shows plant cells undergoing cell division.</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>(N =)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
The number of students stating they did not know anything regarding the cell's control and metabolism dropped from 60 percent to 25 percent after instruction (Table 33). The 4 students holding the conception that the nucleus controls the cell prior to instruction maintained this conception after instruction. The number of students holding alternative conceptions falling into category 3 (chromosome, gene, or hormone control of the cell) increased by 2 students. The conception that the amount of material absorbed by the cell controls its division was found only after instruction and was held by 40 percent of the students.

**TABLE 33**

| Categories of conceptions regarding cell control and metabolism and the number of students identified in each category |
|---------------------------------------------------------------|------|------|
| i. I do not know.                                             | 12   | 5    |
| 1. A person's brain controls cells.                           | 3    | 0    |
| 2. The cell has a brain (or nucleus) which controls it.       | 4    | 4    |
| 3. The cells chromosomes or genes and hormones control it.    | 1    | 3    |
| 4. The amount of material absorbed by the cell controls its division. | 0    | 8    |

N = 20  20
Student conceptions of the concepts of mitosis and meiosis prior to instruction were not present. Both of these concepts were presented to all of the students in the sample during instruction. After instruction students' conceptions were classified into 6 general categories (Table 34). Two students held conceptions that could be considered as basic scientific conceptions with respect to both concepts. A further 9 students were found to hold a basic scientific conception of mitosis but not of meiosis. The other 11 students (55%) held alternative conceptions which did not reflect an understanding of the conceptions as it had been presented during instruction.

**TABLE 34**

<table>
<thead>
<tr>
<th>Categories of conceptions regarding mitosis and meiosis and the number of students identified in each category</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>1. One of the two (mitosis or meiosis) occurs in animals and the other one in plants.</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2. One of the two produces more cells than the other.</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3. One of the two occurs in animals and the other in plants and one of the two produces more cells than the other.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4. Mitosis is the division of cells, meiosis is something else.</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>5. One of the two is asexual reproduction and the other is sexual reproduction.</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
TABLE 34 (continued)

Categories of conceptions regarding mitosis and meiosis and the number of students identified in each category

<table>
<thead>
<tr>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

6. Mitosis is the process of dividing of cells into new cells, excepting the gametes. In mitosis you get two diploid cells from the parent that are identical. Meiosis is the division of sex cells, first you get 4 cells with random chromosomes. The chromosomes double in the first cells and it divides twice to give you 4 haploid cells.

N =

Table 35 presents the results of students' identification of a specimen an of onion root with cells in various stages of mitosis viewed under a microscope. It also presents the results of their identification of a photomicrograph of onion root tip cells undergoing mitosis. All of the students without exception studied, observed and made drawings of a similar specimen and photomicrograph during instruction. Fifty percent (10 students) of the sample identified the specimen correctly as plant cells after instruction. Of these 10 students, all cited reasons for their identification. Eight students (40%) identified the specimen simply as cells, 1 student identified it as an animal cell, while 1 student did not know what the specimen was.
With respect to the photomicrograph of the same cells, 55 percent (11 students) were again able to identify the objects as plant cells, all of them offering the shape of the cell as a reason for their identification. The 8 students that identified the specimen simply as cells identified the photomicrograph as animal cells, citing no specific reasons.

**TABLE 35**

**Specimen and photomicrograph identification and the number of students identified in each category**

<table>
<thead>
<tr>
<th>Specimen</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1. The specimen is a cell.</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>2. The specimen is a blood cell.</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3. The specimen is an animal cell.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4. The specimen is a plant cell because of its shape.</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>5. The specimen is a plant cell because it is green in colour due to chloroplasts.</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ N = 20 \quad 20 \]

<table>
<thead>
<tr>
<th>Photomicrograph</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. I do not know.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1. The photomicrograph is of a living object.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2. The photomicrograph is of an organism's cells.</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>3. The photomicrograph is of an animal's cells.</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>
TABLE 35 (continued)
Specimen and photomicrograph identification
and the number of students identified in
each category

<table>
<thead>
<tr>
<th>Photomicrograph</th>
<th>10b</th>
<th>10a</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. The photomicrograph is of a</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>plant's cells because of their</td>
<td></td>
<td></td>
</tr>
<tr>
<td>shape.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N =</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

5.4 General Discussion of Changes in Conceptions

5.1.1 Introduction

This section summarizes the results that have been presented above and relates them to both the research questions and assumptions discussed in Chapter 1 with respect to changes in students' conceptions of growth and the cell after instruction.

The results presented in this chapter provide sufficient evidence to suggest that all the elements of a students' conception of growth or the cell do not change all together after instruction. The majority of students' conceptions changed in some constituent concepts while in others they remained stable from before to after instruction. In comparing the ICIs of all of the 31 students at both levels, none of the students were found to hold persistent alternative or scientific conceptions across all constituent concepts for either growth or the cell.
Similarly, no students were identified who changed all of their alternative or scientific conceptions across all constituent concepts for either growth or the cell. These findings suggest that the acquisition of knowledge regarding the concepts of growth and the cell does not simply involve the wholesale replacement of existing conceptions with new conceptions.

Also, while the students were exposed to the scientific concepts of growth and the cell through a variety of instructional activities, the results do not suggest that the majority of students changed their alternative conceptions to scientific conceptions after this instruction. The vast majority of students changed from one alternative conception to another, sometimes to a more developed category and in fewer cases to a less developed category. The minority of students holding scientific conceptions with respect to a number of the constituent concepts were identified as holding those conceptions before instruction.

While the methods of this study do not allow a direct causal link to be drawn between instruction and conceptual change or lack thereof, it is apparent that a majority of students do not hold developed scientific conceptions of growth and the cell after explicit instruction in these concepts. The model viewing the learner as a blank slate upon which complete scientific conceptions need only be
efficiently written is not supported by this research.

It was argued in Chapter 1 that current curricula in biology, both at the elementary and secondary level, were developed at least implicitly under two assumptions:

1. That the student will incorporate the conceptions presented in the materials into his cognitive structure without alteration or modification.

2. That the new conceptions will persist over time and be resistant to change.

The results of this study suggest that these assumptions are not valid.

Furthermore, the students in this sample were not found to hold a conception of differentiation, nor did they all link the concepts of the cell and cell division at the microscopic level to the concept of growth at the macroscopic level. Hackling and Treagust (1982), using a semi-structured interview with 48 students who had completed a grade 10 genetics unit, report similar results. They found that only 48 percent of their sample comprehended growth as being the result of the process of cell division. While the majority of students in this study did make this link with respect to animals after instruction, the majority did not with plants.

5.4.2 Changes in the Conceptions of Growth

The remainder of this section will examine the categories of conceptions before and after instruction in
more detail. Students completing instruction in biology in grade 10 held similar conceptions regarding the parameters of growth at a general level to those held by students prior to instruction in elementary school. An increase in size was seen to be the primary determinant of growth at the elementary level while an increase in size and a change in appearance were the primary determinants at the secondary level.

The criterion of "living" as a parameter of growth was found as a conception only at the elementary level. None of the grade 10 students used living as part of this conception, even after instruction. When asked about the nature of the seed, before instruction, 35 percent of the grade 10 students held that the seed was non-living. After instruction this number increased to 70 percent of the students. It appears from these results that the concept of life itself is not well developed in these students. This difficulty can be predicted in that the criteria for life are abstract rather than being based firmly in everyday experience. As discussed in the previous chapter, Brumby (1981, 1982) has found student difficulties with respect to the concept of life to persist at the university level.

These results also suggest that the methods whereby students study growth and the cell in the classroom may not contribute to their understanding or conceptions regarding the phenomena in a way predicted by the materials. The
instructional experience at both the elementary level (growth) and the secondary level (cell) is structured primarily around plants. It is with reference to animals, particularly humans, that the greatest number of students' conceptions regarding cell division approach scientific conceptions. It may be that grade 10 students' participation in the human reproduction unit provided them with opportunities for establishing a link between their microscopic studies of the cell and their macroscopic conceptions regarding animals. The unit on reproduction did not include plants.

It should also be noted that while a shift toward a conception of growth in animals based on cell division was identified after instruction, this conception was incomplete. The students made no mention of DNA replication, cell growth, or cell death and replacement. These concepts were discussed during instruction but the students' conceptions did not appear to reflect them.

The conception that water and soil are food for plants was found to increase in frequency over time in the elementary school students. Prior to and three weeks after instruction, 45 percent of the grade 3 students held this conception. Eighty-seven percent of the same students held this conception 2 years later.

The number of students holding a conception which saw the materials in plants as changing inside the plant
remained relatively constant over the three interviews (4, 2, and 3, respectively) The number of students holding conceptions in which the materials were viewed as "pushing out" on the organism increased from 2 to 5 after instruction and then decreased to 4 students after 2 years. In animals, the number suggesting that materials change inside animals remained the same (3) while the number holding a "push out" conception increased from 4 to 5.

These findings are significant in the light of the changes in conceptions identified after instruction at the elementary level with respect to the necessities for the instigation of growth in plants. The number of the 11 students holding conceptions in which water was the prime requirement for the instigation of growth increased from 5 before instruction to 10 after. This emphasis on water as the primary requirement and the conception held by students that growth is simply an increase in size could easily lead to the conception that growth is the result of water filling the organism and pushing out on its sides. This suggestion is supported by the finding that some of the students used a balloon as an explanatory model for plant growth after instruction.

Prior to instruction at the grade 10 level, 40 percent of the students stated that they did not know what happened to the materials required for growth after they entered the plant. Twentyfive percent of the students in the sample
invoked the "push out" model discussed above for plant growth. The number of students stating they did not know decreased by 3 after instruction, 2 of these students held that photosynthesis is responsible for growth while the other held that cell division is responsible for growth. For animals, the percentage of students holding a conception involving the "push out" model dropped from 50 percent to 25 percent after instruction while the percentage of students holding a conception based on cell division increased from 25 percent to 70 percent.

Conceptions of the instigation of growth in animals at the elementary level were fairly constant over the 3 interview periods, the majority lacking the notion of egg and sperm. This is significant if it is identified in a larger sample, especially with respect to family life education. Only 40 percent of the grade 10 students prior to instruction and 55 percent after instruction include two individuals or gametes in their conception of the instigation of growth.

The conceptions of students at the elementary level regarding the cessation of growth were mixed but in both plants and animals contained a notion of growth stopping for some reason external to the organism. At the grade 10 level students holding the conception that growth stops when cells stop dividing increased for both plants (1 to 7) and animals (6 to 10).
In instruction, it is assumed that when students learn that cells divide to produce more cells, they will comprehend that most types of cells then die and are constantly replaced during the lifetime of the organism. That this is assumed is clear from the fact that this idea is not mentioned in the learning objectives nor was it explicitly stated by the teachers. These results suggest that the students may draw another valid conclusion based on the information made available to them, namely, that cells divide until the organism has the full complement it requires and that division then stops.

5.4.3 Changes in the Conceptions of the Cell

Conceptions of cell differentiation were found to change insofar as the number of students holding some notion of preformation decreased and the number of students suggesting mitosis increased. Very few of the students, however, held a conception which included the idea of a change in the cells during early development. The assumption, therefore, that the majority of students will construct a concept of differentiation independent of instruction also appears to be unfounded. These results suggest that the majority of students leave grade 10 without a scientific conception of how an organism originates or develops, in spite of an activity filled unit of instruction related to human reproduction.

While the ability of students to recognize cell
division in a photomicrograph increased after instruction, the correct identification of the specimens was surprisingly low. After observing, drawing, and discussing the plant cells during instruction, 45 percent (9 of 20 students) of the sample could not identify the specimen 3 weeks later. Nine of the 10 students who were unable to make a correct identification of the specimen were also unable to correctly identify the cells in the color photomicrograph as plant cells. While the investigator did not make a detailed study of the instruction the students from the 4 classes received, all of them were observed participating in microscope exercises utilizing onion root tip cells similar to the ones utilized in the protocol. Students in all 4 classes drew the cells and discussed the features which identified them visually as plant cells, namely shape (due to a rigid cell wall) and colour (due to the chloroplasts). A more detailed study of the effectiveness of the observational activities using the microscope and subsequent drawing is called for if only 55 percent of the students are able to identify a plant cell after these exercises.

The most extensive changes from before to after instruction occurred with respect to students' conceptions of mitosis and meiosis. During instruction both of these conceptions were discussed within the context of reproduction. The stages of mitosis were discussed and observed in prepared specimens of onion root tip cells in
all classes. Meiosis was discussed within the context of human reproduction, illustrating the stages through drawings of oogenesis and spermatogenesis.

All of the students prior to instruction answered that they had no conceptions regarding these concepts. After instruction all of the students were found to hold conceptions regarding the concepts. Nine of the 20 students were found to hold a basic scientific conception of mitosis, although only 2 were able to name some of the stages in the cellular process. Only 2 of the 20 students were found to hold a basic scientific conception of meiosis. The other alternative conceptions included various components of the instruction in which the students had participated. These components included mitosis and meiosis occurring in different kinds of organisms, producing different numbers of cells, and being related to different forms of reproduction.

The findings related to the concepts of mitosis and meiosis are especially important in that students had no conceptions regarding these concepts prior to instruction. Based upon the assumptions of student learning reflected by the curricular materials, one would predict that the majority of students would have incorporated the information presented through instruction and hands on experiences to form well elaborated scientific conceptions of mitosis and meiosis. Based upon the results of this study, this prediction is clearly not supported in the majority of
students. Stewart and Dale (1981) reached the same conclusion regarding meiosis while Hackling and Tregust (1982), found that only 23 percent of the students in their sample could recall that mitosis was associated with growth, shortly after instruction.

In a general sense, and more specifically with respect to mitosis and meiosis, alternative conceptions have not all changed to scientific conceptions after instruction. The result of this lack of change may manifest itself as student learning difficulties which generally only become apparent during evaluation. The frustration that these difficulties create may drive students away from biology holding alternative conceptions that they may have little opportunity to modify in the future.

For those students continuing in biology, the alternative conceptions may well persist and later develop into learning difficulties when the student encounters higher level concepts which require scientific conceptions of growth, the cell, mitosis, meiosis, differentiation, and a host of other related concepts. On the basis of the limited literature in this area (Chapter 2) and my own classroom experience in teaching Biology 11, student learning difficulties abound in areas such as evolutionary theory, genetics, and plant function, all of which are very dependent on scientific conceptions of the concepts discussed above.
CHAPTER SIX

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

6.0 Overview of the Study

In order to investigate students' alternative conceptions of growth and the cell as possible sources of learning difficulties in biology, two interview protocols were developed in order to elicit students' conceptions regarding these two concepts. A conceptual analysis of these concepts was first carried out with the aim of identifying specific characteristics which define the constituent concepts of growth and the cell as they are currently used by the scientific community. The two interview protocols were developed on the basis of these characteristics, the Growth Protocol for use at the elementary level and the Cell Protocol for use at the secondary level. The Cell Protocol also included some of the growth characteristics from the Growth Protocol.

The Growth Protocol was used to interview students in grade 3 prior to, 3 weeks after, and 2 years after their
first instruction in the concept of growth. Two other groups of students, 10 in grade 5 and 10 in grade 7, were also interviewed using this protocol. The cell protocol was used to interview 20 grade 10 students prior to and 4 weeks after instruction in the cell. The details of the protocols and the sample are discussed in Chapter 3.

The transcripts collected through the use of the protocols were analysed and reduced to Individual Conceptual Inventories (ICIs). As discussed in Chapter 4, each transcript was reduced to a number of individual conceptions related to the constituent concepts of growth and the cell. Students' alternative and scientific conceptions were identified in these ICIs. Both common and individual conceptions were then compiled from the ICIs into Composite Conceptual Inventories (CCIs) organized on the basis of the constituent concepts of growth and the cell. The CCIs provided a catalogue of alternative and scientific conceptions held by the sample with respect to the concepts under investigation. Numbers of students holding the alternative and scientific conceptions were tabulated. These tables provided a measure of the frequencies of the various scientific and alternative conceptions held by the students in the sample.

Based on these tables, a number of categories of conceptions were constructed for each constituent concept and the frequencies of these categories of conceptions were
again tabulated. These categories represented patterns of conceptions held by the students in the sample. Generalizations drawn from these patterns were used to address the first two research questions posed in this study.

In order to examine if the conceptions held by students before instruction were different from those they held after instruction, the frequency of the categories of conceptions before and after instruction were compared. Comparisons were made at both the grade 3 level with respect to the concept of growth and at the grade 10 level with respect to the concepts of growth and the cell. The results of these comparisons, as discussed in Chapter 5, were the basis for formulating the generalizations used to address the third and fourth research questions of this study.

6.1 Conclusions of the Study

The following are the tentative conclusions of this study as they relate to the research questions stated in Chapter 1. Due to the nature of the limited sample of students caution must be used in applying the conclusions to the population of students as a whole.

Research Question 1: What are students' conceptions of growth in plants and animals in grades 3, 5, 7, and 10?

1.1 Children are capable of constructing knowledge
regarding growth in living things prior to formal instruction at the grade 3 level. The majority of the conceptions held by children at this level can be identified in more than one child suggesting that there are similarities in the ways children construct their conceptions. Conceptual categories were constructed which reflect these similarities in students' conceptions with respect to the concept of growth. The conceptual categories which were identified in grade 3 prior to instruction are listed below.

The parameters of growth:

a. Growth is identified primarily as an increase in size.

b. Growth is identified as an increase in size but also a change in appearance.

The sources and acquisition of requirements for growth:

a. Water and soil are the food of the tree and come from the outside, move through the roots and up into the branches and leaves.

b. Water and soil are the food for the tree and come in from the outside, move through the roots, and up into the branches and leaves. Light has a secondary function.

c. Food and water are the primary requirements for growth. These go from the mouth to the heart, intestine, or stomach.

The uses of the requirements for growth:

a. The materials, primarily water, go into the plant and push out on the parts causing them to expand and grow.

b. Materials change into something else when they enter the plant and make it grow.
c. Food and liquids go to the body forcing it outwards and increasing its size.

d. The materials upon entering the body are changed into blood, which causes the muscles and/or the bones to grow, stretching out the skin, or pushing out the parts.

The instigation of growth:

a. Plants start as seeds and need things not including water to grow.

b. In order for plants to begin to grow, a seed need only be supplied with water.

c. In order for plants to begin to grow, a seed needs water and other requirements.

d. A person starts life as a baby in the mother and is supplied with food.

e. A person starts life as an egg, food is supplied by the mother.

The cessation of growth:

a. Plants stop growing in an upward direction for a variety of reasons.

b. Plants do not stop growing, they grow slowly.

c. Plants stop growing when they die.

d. Animals stop growing for some reason but go on living.

e. Animals do not stop growing until they die.

These conceptual categories identified at the grade 3 level prior to instruction represent primarily alternative conceptions of growth. The alternative conceptions reflect knowledge which appears to be based on the practical and linguistic experiences which the children have encountered with the phenomena of growth.
In plants, for example, water is seen as the primary requirement for seed germination and together with soil, it is seen as food for the plant. Light has some secondary function at best. This view is consistent with the everyday experiences of watering plants and possibly planting seeds in a garden. There is very little empirical evidence to suggest to the observer that light is necessary to create the food for the plant.

The children at this level have either no conception or a very limited conception of how food is changed into an increase in the size of living things. In both plants and animals the conception of food "pushing out" or "forcing out" the parts of the organism is the one most frequently identified. This conception appears to be a valid descriptive attempt at drawing a connection between food and the increase in size based on the evidence available to the child. The notion of a change in the food is found for both plants and animals although it is not elaborated in plants. Those children stating that food in animals is turned into blood and then into bone and muscle follow this up with the "stretching of skin" or the "pushing out" of parts conception.

This absense of a clear sense of cause or mechanism with respect to growth is evident in the
majority of conceptions at this level. While a person is described as beginning as a baby or egg which obtains its food from the mother, nothing can be identified which relates the food to an increase in the size of the baby or egg. It appears therefore, that children prior to instruction construct conceptions based primarily on descriptions of the phenomena of growth rather than its mechanisms.

1.2 The conceptual categories identified in grade 3 prior to instruction were also identified (in the sample without exception) at the grade 5, grade 7 and grade 10 levels. This strongly suggests that the descriptive, experientially based alternative conceptions which these categories represent are very successful in allowing students at all levels to deal with the everyday phenomena of growth. The persistence of these alternative conceptions also suggests that they may be more useful to the student than the scientific conceptions regarding the concept of growth which they encounter at the various grade levels.

1.3 Additional conceptual categories were identified with respect to the concept of growth by the end of elementary school (grade 7). These include the categories listed below.

The parameters of growth:

a. Being alive is a primary parameter of growth.
b. Having cells is a primary parameter of growth.

The sources and acquisition of requirements for growth:

a. The material that enters the tree is changed and this changed material is the food for the tree. The sun is involved in a general sense and enters through the leaves.

b. The material that enters the tree is all necessary for growth, but the sunlight somehow involved with photosynthesis is the most important.

c. Food and water are the primary requirements for growth. These go from the mouth to the stomach and are then changed, and then go to the body.

The uses of the requirements for growth:

a. Photosynthesis is responsible for growth in plants.

b. Photosynthesis supplies the food necessary for cells to divide which results in the growth of the plant.

c. The nutrients in the blood supply the cells which grow bigger or somehow increase in number, causing the bones to grow and the parts to get bigger.

The instigation of growth:

a. Plants start as parts cut or fallen off other plants. These get in the soil and grow.

b. A person starts life as an egg fertilized by a sperm, food is then supplied by the mother.

The nature of seeds:

a. Seeds are non-living when they are not growing.

b. Seeds are dormant when they are not growing.

c. Seeds are alive when they are not growing.

The cessation of growth:

a. Animals stop growing, and this is controlled by
something in the animals. Animals then go on living.

b. Animals stop growing when their cells stop dividing.

At the grade 7 level the concept of growth is associated with not only an increase in size but also with the cell and the notion that the organism is alive. The importance of sunlight for plant growth is first associated with the process of photosynthesis. The scientific conceptions that photosynthesis supplies the food necessary for cell division in plants and that nutrients in the blood serve the same function in animals can also be identified at this level. The conception that living things are composed of cells is also clearly represented at this level.

In a number of cases it appears that students have included mechanisms in their conceptions. For example "photosynthesis supplies the food necessary for cells to divide which results in the growth of the plant" clearly demonstrates a scientific conception including a mechanism for growth. In other cases, however, students have simply provided a concept name without providing evidence that they actually understand the construct to which the name refers. The category "photosynthesis is responsible for growth in plants" is an example of this. When asked to elaborate, students invariably responds with "I do not know".
Since students have conceptions of growth at the grade 7 level which include concepts such as cell, cell division, and photosynthesis, it seems clear that some students have incorporated new conceptions encountered in instruction. A judgement based on the limited sample used in this study, however, suggests that only a small minority of students will hold these new scientific conceptions. Furthermore, students identified as holding a scientific conception related to one constituent concept will not necessarily hold scientific conceptions related to other constituent concepts of growth.

These results reinforce the conclusion that conceptions constructed on the basis of experience which allow the student to deal practically with the world will not necessarily be replaced by scientific conceptions provided during instruction which are intended to allow them to more effectively explain the world.

1.4 A number of further conceptual categories related to growth can be identified in grade 10 prior to instruction. These include the categories identified below.

The parameters of growth:

a. Cell division is the microscopic explanation for growth at the macroscopic level.
The uses of the requirements for growth:

a. The nutrients supply the cells with energy allowing the cells to divide, creating more cells, and thereby growth.

The instigation of growth:

a. A person results from an egg being fertilized by a sperm, which then grows as a result of division nourished by nutrients from the mother.

The cessation of growth:

a. Plants stop growing when cells stop dividing.

The three new categories of conceptions identified at the grade 10 level reflect somewhat more elaborated scientific conceptions than those identified at the grade 7 level. It is evident that students at the grade 10 level have been exposed to scientific concepts regarding growth and that they are capable of constructing conceptions which include these concepts. As at the grade 7 level, however, in this sample of grade 10 students only a small minority of students include scientific conceptions in their conceptions of growth.

Research Question 2: What are students' conceptions of the cell in grade 10?

2.1 Student conceptions of the cell prior to formal instruction in the concept at the secondary level (grade 10) were identified. Similarities between students in the construction of these conceptions can be stated in terms of the following conceptual
categories:

Cell Differentiation:

a. The different parts of a person originate from cells already present when the person is conceived.

b. The different parts of an organism originate from cells going through mitosis and being changed in some manner.

The cell's relation to growth:

a. Cells deliver nutrients to the body.

b. Growth in animals is caused by cells dividing while growth in plants is caused by cells filling up.

c. Cells increase in size causing growth.

d. Cells divide causing growth.

The cell's interaction with body functions:

a. Cells are not involved in body functions.

b. Cells are involved in body functions.

c. Nerve cells are involved in all body functions and carry messages.

Cell control and metabolism:

a. A person's brain controls cells.

b. The cell has a brain (or nucleus) which controls it.

c. The cell's chromosomes, genes, or hormones control it.

Students' interpretation of a photomicrograph of mitosis in onion root tip cells:

a. Nothing related to growth is occurring in the photograph.

b. The photomicrograph shows cells from different organisms.
c. The photomicrograph shows cells from different organisms dividing.
d. The photomicrograph shows different kinds of cells from the same organism.
e. The photomicrograph shows different kinds of cells from the same organism dividing.
f. The photomicrograph shows plant cells undergoing cell division.

Students' identification of onion root tip cells in a specimen:

a. The specimen is a cell.
b. The specimen is a blood cell.
c. The specimen is a plant cell because of its shape.
d. The specimen is a plant cell because it is green in colour due to chloroplasts.

Students' identification of onion root tip cells in a photomicrograph:

a. the photomicrograph is of a living object.
b. the photomicrograph is of an organism's cells.
c. the photomicrograph is of an animal's cells.
d. the photomicrograph is of a plant's cells because of their shape.

2.2 Students in grade 10 hold a wide range of conceptions related to the cell. Students were also identified who have no conceptions regarding many of the constituent concepts of the cell, more so than in the case of the concept of growth. The construction of a scientific conception of the cell does not necessarily occur when one observes and interacts with growing, living things. This may in part explain the difference in the
number of students who stated they had no ideas related to many of the constituent concepts of the cell prior to instruction as compared to the concept of growth.

The students' conceptual categories identified at the grade 10 level prior to instruction may reflect attempts at constructing conceptions regarding an abstract concept based upon incomplete information obtained from a variety of experiences both in and out of school. The majority of students can identify a cell in a specimen but are unable to classify it as a plant or an animal cell. Some students recognize that living things are made up of cells and that these cells are involved in the growth and functioning of organisms.

Many alternative conceptions attempt to address the mechanisms whereby cell processes take place. For example, both conceptions regarding cell differentiation include the notion of cells originating from other cells. How it is that different cells originate from the original cells is unclear. In both conceptual categories the question of a mechanism for creating different cells is not addressed. In the first, the cells are already present to begin with, while in the second the mechanism for making more cells is stated as the mechanism for making different cells.
As another example, terms such as brain, nucleus, chromosome, gene, and hormone are used in conceptions related to the control and metabolism of cells. As was encountered at the grade 7 level, however, students seldomly provide an elaboration of these terms or the processes to which they relate.

Research Question 3: Do the grade 3 students' conceptions of growth change after instruction in science?

3.1 All of the grade 3 students' conceptions of growth identified in the conceptual categories before instruction were identified after instruction. In addition to these categories, 3 new categories of conceptions were identified after instruction.

a. Being alive is the primary parameter of growth (identified 3 weeks after instruction and again 2 years later).

b. The material that enters the tree is changed and this changed material is the food for the tree. The sun is involved in a general sense and enters through the leaves (identified 3 weeks after instruction only).

c. Photosynthesis is responsible for growth in plants (identified 3 weeks after instruction only).

During instruction students participated in a variety of activities involving plants and trees in both the classroom and their home environment. Seeds were grown under a number of different conditions and the students participated actively in discussing the results of these activities. The teacher carefully
attempted to lead the children to understand that the poor growth in plants raised in a dark cupboard was a result of a lack of light. She explained that light supplied energy to the plants through a process called photosynthesis which made food for plants.

Some students held conceptions which approximated to some extent the scientific concepts introduced during instruction. The results of this study suggest however, that the simpler, concrete, conceptions identified before instruction are more persistent than the new ideas. Two lines of evidence point to this conclusion, the first being the small number of students who were found to hold the more scientific conceptions after instruction as compared to those holding the alternative conceptions.

Secondly, in a number of cases the increase in the number of students holding a scientific conception 3 weeks after instruction is not maintained two years later when the students are in grade 5. For example, the two conceptual categories first identified three weeks after instruction related to the necessity of the sun and photosynthesis for growth in plants were not identified in the same students two years later in grade 5.

It is interesting to note that 75 percent of the grade 10 students interviewed in this study, when asked
what they remembered about experiments with growth in school, stated that they learned that while plants could grow in the dark, they did not grow very well. If these comments accurately reflect the observations the students made at the elementary level, instruction itself may be reinforcing alternative conceptions related to the acquisition of food in plants.

In another example, the increase in the conceptual category stating that plants need not only water to grow but other requirements as well increased after instruction from 9 percent to 64 percent of the sample. The same conceptual category was identified in only 25 percent of the sample when they reached grade 5.

Research Question 4: Do the grade 10 students' conceptions of growth and the cell change after instruction in science?

4.1 The majority of grade 10 students' conceptions regarding growth and the cell identified in the conceptual categories before instruction were also identified after instruction. The conceptual categories which were not identified after instruction represent primarily alternative conceptions.

The following new conceptual categories were identified after instruction in the cell:

a. Cell division is responsible for growth in plants.

b. The different cells originate by going through mitosis but I do not know how the differences in
cells arise.

c. The amount of material absorbed by the cell controls its division.

d. One of the two (mitosis or meiosis) occurs in animals and the other one in plants.

e. One of the two (mitosis or meiosis) produces more cells than the other.

f. One of the two (mitosis or meiosis) occurs in animals and the other in plants and one of the two produces more cells than the other.

g. Mitosis is the division of cells, meiosis is something else.

h. One of the two (mitosis or meiosis) is asexual reproduction and the other is sexual reproduction.

i. Mitosis is the process of dividing of cells into new cells, excepting the gametes. In mitosis you get two diploid cells from the parent that are identical. Meiosis is the division of sex cells, first you get 4 cells with random chromosomes. The chromosomes double in the first cells and it divides twice to give you 4 haploid cells.

The conceptual categories identified after instruction at the grade 10 level generally reflect the scientific conception that living things are made up of cells and that growth is the result of cells dividing into more cells. The latter conception was identified more frequently with reference to humans than with reference to plants.

4.2 The following conceptual categories were identified prior to instruction but not after instruction:

a. Food and liquids go to the body forcing it outwards and increasing its size.
b. A person starts life as a baby in the mother and is supplied with food.

c. A person results from an egg being fertilized by a sperm, which then grows as a result of cell division nourished by the mother.

d. Cells deliver nutrients to the body.

e. The photomicrograph shows cells from different organisms.

f. The photomicrograph shows cells from different organisms dividing.

g. A person's brain controls cells.

h. The specimen is a blood cell.

i. The photomicrograph is of a living object.

The student holding the scientific conception identified in (c) above before instruction was found to hold the conception "A person starts life as an egg fertilized by a sperm, food is then supplied by the mother" after instruction. Her transcript unfortunately provides no information on why the notion of cell division was dropped from her conception. None of the other students in the sample were found to hold a conception of the instigation of growth which included cell division. It may be that the absence of a conception of cell differentiation contributed to this result.

4.3 Not all students after instruction hold a concept of mitosis which includes cell division. Only 50 percent of the students in this study identified cell division as involving the process of mitosis. There are other
notable omissions evident in students conceptions of mitosis which prevent them from being classified as scientific conceptions. In those categories which include cell division as a component of mitosis, the concepts of replication of genetic material and increase in size of the cell after division are not evident. Details of the cell cycle are not included in any of the conceptions. Furthermore, growth is viewed as being a result of cell division continuing until a certain maximum size for the organism is reached. The notion that growth is the result of continuous cell division, cell growth, and cell death is not present in the conceptions of students after instruction.

4.4 A clear conception of how the different parts of an organism originate from the one fertilized egg is also conspicuously absent. The scientific concept which encompasses this phenomena is cell differentiation, in which daughter cells arise which are different from each other and from the parent cell. The critical distinction is that the differences are in morphology and function and not in genetic constitution. During instruction, mitosis is usually defined in a broad sense as the production of identical daughter cells from a parent cell. If the distinction stated above is not made explicit it is likely that students will have difficulty in constructing a conception of development
which involves mitosis because the two concepts will appear contradictory. This may explain the results obtained in this study.

4.5 Only a minority of students hold a scientific conception of meiosis after instruction in the concept. Of the six conceptual categories identified which include meiosis, five represent alternative conceptions. The alternative conceptions appear to be attempts by students to link an appropriate process with the concept name "meiosis".

6.2 Educational Implications

The findings of this research, although tentative, have implications for both classroom practice and curriculum development. Gilbert, Osborne, and Fensham (1982) argued that classroom instruction should aim towards a "unified science outcome" as the desired result of the interaction between children's science and teachers' science. The results of this study suggest that this outcome may not be met in many students with respect to the concepts of growth and the cell.

Teachers must therefore be made aware that students bring alternative conceptions to the learning situation which may influence the way in which the students interpret the scientific concepts discussed during instruction. This improved awareness could be achieved through a number of
different strategies:

1. Presenting research results and conclusions in clear terms at local, provincial, national, and international teachers and administrators conferences.

2. Orienting the presentation of research results and conclusions to problems of instruction and learning difficulties and presenting them in local and provincial teachers journals.

3. Initiating workshops for both teachers and curriculum developers demonstrating the importance of students' prior knowledge and how instruction interacts with it.

4. Developing university undergraduate and graduate programs which include courses which actively deal with problems in this area.

Knowledge of students' prior knowledge will allow teachers to make adjustments in their teaching strategies in order to better facilitate the transition from alternative to scientific conceptions.

For example, a teacher knowing that the majority of students in his grade 3 class have an alternative conception prior to instruction which views soil as the food for plants will be able to design instructional situations in which this conception may be made untenable at the practical level. One approach he could use would be to have his students predict what would happen if they grew plants only in water and light. After successfully growing the plants under these conditions, the students should then be challenged to examine their predictions and draw conclusions from their observations. This exercise is simply a modification of a classic elementary science experiment.
related to controlling variables. The difference lies in the fact that the teacher uses a specific part of the experiment to address specific student conceptions rather than presenting the concept of growth as an aside in order to teach students about controlled experiments.

Similarly, a teacher at the grade 10 level who is aware that the majority of her students hold alternative conceptions of mitosis and meiosis may decide to spend less time on detailed presentations of the stages of these processes and more time on developing the general ideas of mitosis as the mechanism of growth and meiosis as the mechanism for the production of gametes. If the majority of students were found to hold a "fill up" model or "push out" model for growth and no conception of cell division, the same teacher might decide to dispense with meiosis completely and simply deal with growth.

In order for the teacher to identify student conceptions, however, an effective methodology must be available. Using the interview protocols developed for this study with regular classes within the constraints of a regular teaching appointment would be impossible. One solution for overcoming this time problem would be to develop a multiple choice or short answer instrument based on the categories of conceptions identified in Chapter 4. An analysis of the responses on such an instrument would present the teacher with information regarding the
conceptions of the students which could be used at both the
group and individual level. It is imperative, however, that
the students be made aware that the instrument is not being
used for regular course evaluation. An anonymous approach
would have the advantage of producing a more reliable result
but would only provide an overview of the conceptions held
by the class as a whole. The teacher might not find this a
sufficient basis on which to make instructional decisions.
The most effective solution would be to develop an attitude
of trust between the teacher and the students in which the
latter viewed all components of learning, including
evaluation, as a cooperative venture.

The results of this study suggest that failure to take
students' alternative conceptions into consideration prior
to instruction may result in the persistence of these
alternative conceptions in spite of exposure to scientific
concepts during instruction. A student's commitment to an
alternative conception may lead to conflict when the student
is forced to accept a scientific concept during instruction.
This conflict may manifest itself as a learning difficulty.
Student learning difficulties have been identified with
respect to the concepts of growth (Hackling and Treagust,
1982; Okeke and Wood-Robinson, 1980) and the cell (Hackling
and Treagust, 1982; Marek, 1984; Okeke and Wood-Robinson,
1980). This study is an important addition to this body of
research in that it identifies potential sources for these
learning difficulties at both the elementary and secondary school levels.

There is also the possibility that students may compartmentalize their classroom learning and not apply it as a model with which to understand the real world. This is the "two perspectives" outcome suggested by Gilbert, Osborne, and Fensham (1982). In the classroom this outcome would be more difficult to identify than the conflict situation discussed above. For example, while only 2 students had scientific conceptions of both mitosis and meiosis after instruction, the results of the 20 grade 10 students on the post unit classroom tests averaged 68 percent with 2 failures (the students were from 4 different classes with four different teachers). At the time of the classroom tests the students evidently responded with some elements of scientific conceptions of mitosis and meiosis. Two weeks later however, only two responded with scientific conceptions. This result might be explained by the students holding two sets of conceptions, one being the "facts" they commit to memory in the form of propositions for tests while the other are alternative conceptions used to interpret real world phenomena.

This conjecture may also explain the changes in grade 3 students' conceptions with regard to seed growth and the necessity of light for growth in plants. While a number of students were found to hold a basic scientific conception
regarding these constituent concepts immediately after instruction, the same students in grade 5 predominantly used the same alternative conceptions which they had used prior to instruction in grade 3.

Another classroom response to the results of this study would involve teachers carefully examining the concepts they teach for obvious logical omissions and developing lessons to deal with these omissions. Examples of such a response include carrying the plant unit in grade 3 through to completion in order to show that plants do in fact die without light. At the secondary level the teacher may decide to include lessons on differentiation when discussing reproduction and developing the links between growth, cell division, and mitosis explicitly.

The inclusion of exercises based on concrete experiences will also be a way to assist the students in shifting from alternative to scientific conceptions. This researcher is currently exploring this possibility with respect to students' conceptions of mitosis at the grade 11 biology level. This researcher is developing an instructional unit at the grade 11 level which involves an emphasis on the basic constituent concepts of growth.

Included in the exercises are having students generate their own criteria for the concept of "life", growing many different plants and animals, making actual measurements and observations of growth in the various organisms, and
examining the growing parts of living plants through the microscope. The students make the root and leaf preparations which they observe from plants that they are growing. Discussions regarding the cell and mitosis are centered around video images of the process occurring live under a camera. This is an attempt to help them understand that the cell and mitosis are real life phenomena and not inanimate objects on a small piece of glass. The usefulness of computer simulations is also being investigated in this developing unit.

The fruitfulness of this approach is being assessed by means of observations of student performance and discussions with students regarding this unit as it compares to the structured unit in grade 10. Careful analyses of questionnaires addressing their conceptions are providing positive indications that change toward scientific conceptions is being facilitated. Significantly, many students participating in this unit have stated that for the first time instruction appears to be aimed at helping them understand biological phenomena rather than memorize biological facts.

The results of this study also have implications for curriculum development. The extent to which teachers are able to take into account the perspective of the learner relies heavily on the leadership of curriculum developers. Learners are not "blank slates" (Fensham, 1980) with respect
to the concepts of growth and the cell when they first encounter these concepts in the classroom. Rather, these results support Driver and Erickson's (1983) suggestion that many students construct from previous physical and linguistic experience conceptions which they use to interpret phenomena. It is also clear that students' alternative conceptions do not always change to scientific conceptions after instruction. This may in part be the result of curriculum not providing the learner with the conditions Posner et al. (1982) consider essential for this change to occur, namely:

1. There must be dissatisfaction with the existing conceptions.
2. A new conception must be minimally understood or "intelligible".

Curricula in all areas must begin to reflect an orientation towards learning which is centered on the learner as opposed to focussing entirely upon the conceptual structure of the discipline. It is far more important to provide a student with opportunities to construct a coherent scientific conception of "living thing", at the elementary level than providing that student with conceptual snapshots of growth, photosynthesis, electricity, heat, and a host of other unrelated (from the perspective of the student) concepts.
The reasons are twofold, first, the concept of "living thing" is basic, concrete, and based on experience. The student may already possess conceptions related to this concept which can be addressed through instruction. This is not likely to be the case with a concept such as photosynthesis. Secondly, a scientific conception of "living thing" is a necessary prerequisite for a scientific conception of growth or photosynthesis. Unless students have at least some understanding of "living thing", it is unlikely that they will later develop scientific conceptions of the more abstract concepts.

Another implication of this work relates to conceptual coverage and available teaching time. As an example, the grade 8 science curriculum presently covers the concepts of matter, energy, heat, sound, light, senses, the nervous system, drugs, the environment, pests, resources, the planets, the solar system, weather, rocks and minerals, geological change, and biological change. A normal school year realistically provides the teacher with approximately 100 hours in which to "cover" these concepts which span all the realms of science. Furthermore, science is only one of the 8 courses most students take in grade 8, most of which have curricula offering a similar range of concepts.

If instruction is to shift from this "coverage" orientation to one in which the students' scientific understanding of the concepts is paramount, it is clear that
the number of concepts presented at all levels must be reduced. If the teacher is to analyse the conceptions of students prior to instruction and present students with a wide range of opportunities for concrete, hands on experiences with the phenomena in question, curriculum developers will have to drastically narrow the range of concepts serving as the basis of learning objectives in elementary and junior secondary science.

Finally, the basic approach currently used in establishing the learning objectives as they relate to concepts in the science curricula must be modified. Each concept which is chosen for instruction at any level should be subjected to the same sort of conceptual analysis used in this study. Careful consideration must be given to all of the characteristics related to the concept and also the prerequisite knowledge which may be necessary for a reasonable understanding of the concept. Available research on students' alternative conceptions related to the concept should then be consulted or appropriate studies mandated to provide this information if it is not available. Learning objectives and materials should then be developed or chosen on the basis of the findings related to both student conceptions and the conceptual analyses. This approach to curriculum change will prove far more fruitful in providing students with meaningful knowledge related to scientific phenomena than the common model in which disciplinary or
historically entrenched concepts and experiences are rearranged, at times supplemented with current knowledge, and presented in a new format.

As discussed in Chapter 2, the new curriculum framework proposed for the British Columbia school system (British Columbia Ministry of Education, 1989) recognizes the importance of the learner in its statement of principles. A central task for the educational community of this Province over the next ten years will be to develop and implement policies, procedures, and materials in support of the new curriculum which accurately reflect this new emphasis.

6.3 Recommendations for Future Research

It is important that future research related to students' conceptions of growth and the cell be directed in at least the following three major directions.

1. In order to provide the justification for the curricular changes advocated above and the grounds necessary for convincing teachers to change current practice, the tentative conclusions advanced in this study should be confirmed through the use of a larger, more representative sample. The use of the protocols would not likely be a time effective methodology for such studies. The categories of conceptions discussed in Chapter 5 provide a basis for the development of
classroom based instruments which, while not providing the breadth of students' conceptions available through protocols, would provide a way to investigate both alternative conceptions and conceptual change in large groups.

2. The component of the instructional environment that clearly has an enormous impact on students' conceptions (which was outside of the scope of this study) is the teacher. The teacher is the critical interface through which the curricular objectives are interpreted and operationalized in the instructional environment. Teachers are critical in that they determine how the curriculum is implemented in practical terms, including the emphasis, the timing, the experiences, and the affective orientation of the students toward the concepts in question. The teacher's own conceptions regarding the concepts therefore can be expected to have a major impact on students' conceptions. Since teachers themselves are a product of the same educational system as their students, it can be expected that they too will hold alternative conceptions regarding many of the concepts which they teach. A primary responsibility of our teacher education facilities will be to design methodologies which will help teachers identify these alternative conceptions not only in their students but also in themselves.
Teachers must be given the confidence to view this type of self analysis or reflection as an ongoing part of their own learning and professional development.

3. The third direction for research is to investigate directly and in depth the interaction of the curriculum, the teacher, the students, and the instructional environment in specific learning situations regarding the concepts of growth and the cell. This research would provide a clearer picture of the effects of particular learning strategies on specific conceptions held by students. These studies should involve one class of students and the researcher should be present during the entire period the concept is under consideration. An interview protocol such as the one developed in this study should be used and analysed at a more basic level such as that of the Individual Conceptual Inventory. Results from these studies could then be used to develop intervention strategies aimed at helping the students construct scientific conceptions of the concepts under investigation. A great pool of potential researchers well qualified to undertake such investigations already exists in the form of the teachers of this province. Teachers may become interested in becoming involved in these investigations if incentives in the form of time and support are provided by the Ministry of Education.
and the school districts of this Province.

The task of the institutional researcher now is to convince teachers that this area of research and its implications are of paramount importance to providing students with better tools with which to interpret many of the phenomena occurring in their world.
LITERATURE CITED


APPENDIX A

SAMPLE TRANSCRIPTION - THE GROWTH INTERVIEW

Interview: Pre-instruction interview
Subject: Philip
Grade: 3
Age: 9 years 1 month

Key: I# = Question posed by the investigator, (#) indicates interview question number where appropriate
S = Response or comments by the subject

I1 I would like you to have a look at these two pictures here, there you go, and tell me something about what you think is going on in them.
S First, a seed is being buried and at 3 weeks later a plant starts growing and a root forms and 2 months later the root grows because somebody probably poured water into it, its growing into a tree. Two years later its almost a tree but not big enough yet, and 18 years later it forms a tree because the day it was born it was only a little seed and once it gets 10 years it forms a tree.

I2 And what about in that picture?
S You are first born to be a baby, 3 years later you become a boy and 12 years later you become a junior and go to high school, 10 years later you become a man and go to work and 12 years later you become a father of grand children and grandmothers.

I2 I have another picture here that I would like you to take a look at, have a look at this one, what do you think is going on in that picture? First of all, what do you think this thing is?
S I think this is a rock on a beach, lets see, first year it becomes a little rock, when its 7 years it becomes huger, bigger than it used to be, 10 years later it becomes bigger than the other ones, about 5 years ago. Fifteen years later it becomes a boulder and 20 years later it becomes a huge rock that is big enough for a cave.

I2 And what about in this picture?
S First a puppy is like 3 or 4 months later, and then it comes up to be a middle sized puppy and then 7 years later it becomes bigger and bigger and 20 years later it turns into a dog and 25 years later its big enough for a pet.

I3 Ok, so if we look at all of these pictures, like this, what do you think that they all are trying to show?
S They are all trying to show when something is small and
grows up to be a huge thing.

I Is there any of these pictures that is separate from the rest, that doesn't really fit?
S They all show growing things.
I So here the person is growing, is that right?
S Yes.
I Here the tree is growing?
S Yes.
I And the rock is growing?
S Yes it is.
I And the puppy is growing?
S Yes.
I Suppose we had a balloon and I blew that up with air or put it under a tap and filled it up with water, what do you think, is that the same kind of thing that is happening here or is that something different.
S Its the same thing but the balloon could pop any time.
I Is the balloon growing too just like a person grows?
S No.
I It something different then?
S Yes.
I What do you think that difference is?
S That difference is like everything doesn't have to have it blown, it just forms huge when it gets water or air or gets things to eat by the roots.
I3 Supposing we look at these two pictures, what are the main things that tell you something is growing?
S Its growing because the first day these 2 are small things and then 3 weeks the same thing is bigger and then in 2 months this is a junior and in 2 years this is like a man and in 18 years this is like a grandfather.
I What are the things that are happening to the tree or the person that are telling you it is growing?
S Changes, like, it becomes bigger every time. In the first picture this is only a seed, in the second picture it is bigger, in the third picture this is bigger than the little root, in the fourth picture this tree is bigger than the smaller tree here, in the fifth picture this is a tree.
I So its growing bigger. Is a person growing bigger too? What direction.
S Upwards.
I Any other way it is growing bigger?
S Mainly upwards.
I4 Suppose we think about a tree for a moment, what do you think are the most important things a tree needs to grow?
S It needs roots.
I12 What do you think a tree needs ... lets ask the same question about the person, what are the important things a person needs to grow?
Good and healthy food. If a mother was going to have a baby and she drinks too much wine or anything the baby would not grow because she's having a baby and she can't just think of the bad things to eat because the baby might not grow one head because some babies are two heads on one body.

I Right, humm, so food is an important thing to help a person grow. is there anything else that is important?

S Do a lot of exercise and healthy things as you grow.

I How about the same kind of question for a tree, what's important for a tree to grow?

S Water, because if it doesn't have any water, the roots of the tree will just grow brown because if doesn't have water it will die.

I I see. Is there anything else you can think of that is important for the tree other than water?

S The seed, because if you don't have a seed, the tree won't grow.

I How do you think that water gets, does water get into the tree from somewhere do you think?

S Yes, once you pour water on the ground near a tree the roots pick it up from the ground and deliver it from branch to branch so the tree could grow.

I I see. And how does water make the tree grow?

S Um, by itself, because water makes a tree grow and if a tree doesn't have water the branches will just fall off the tree and there won't be any seeds left.

I But we've talked about the water getting in, right, what happens to it once it gets inside the tree?

S Well, first the seed of the roots pick it up and then it delivers it to a branch and once it gets to a branch the leaves pick it up and and it keeps on growing until the trees get torn down by lumbermen.

I Suppose we were able to look inside a tree, what do you think we would find?

S We would find circles that grow around and around, once you count the circles, you'll find out how old it is.

I Oh, I see. Where do you think that stuff that the circles is comes from?

S The root of the tree because every year the tree grows bigger and bigger and the circles inside get more and more.

I When the seed starts little like this does it have some of the stuff that is going to make circles in it?

S Not yet, until it gets almost about 2 years.

I Here the tree is really a little guy and when it gets to here the stump is quite a bit bigger, the stuff that's inside of there, like when you look at the circles when you cut it open, um, that wasn't there at the beginning, where do you think that stuff came from?

S It came from the soil because when the water comes it actually goes into the soil that makes the roots pick
it up and the soil gets into the water and the water lifts it to make the round circles when it grows.

I So you think it's the soil that gets in to make it?
S Yes it is, with the water.

I Do you think this stuff inside the tree is the same as the soil when it is outside the tree?
S No, I don't think so.
I Is there a change there? Something happens to it?
S I don't know. It may be when the roots are picking up, the tree inside, once it gets inside the circles probably form.

I Suppose we have a look at the person, and we said what was important for the person was food, and what else was there?
S Food and exercise, because if you do not have exercise you just get over here (indicates fat person).
I We said for the tree it was important to have soil and water, do you think water is important for the person?
S Yes because water makes you work and if you don't have water you will die of thirst.
I Is water really important then, or did you include it under food?
S If you have fried things it is important to have water with you because sometimes people who eat fried foods get sore throats.
I Is water important for growing then in the person?
S It helps with growing.

I How does food and water get into the person?
S The person uses their hands and a spoon or a fork and eats, like the brain tells them what to do next.
I Ok, so you eat the food, put it in your mouth with a fork or a spoon and what do you think happens to it then?
S Then it goes, like, you chew it up and it goes into 3 groups and 4 groups and more groups and then forms into your body and the things you don't need comes, like, in a little vein that comes down, and if you don't need it then it comes out somewhere.

I So what happens, like these 4 groups you were telling me about, where does the food change into these 4 different groups?
S Once you chew it it changes around your neck or inside your neck.
I And then once it is in, do you have any idea of what these 4 different kinds of groups are?
S Just 4 four plain groups of different kinds of stuff.
I And then what happens to it once it forms 4 groups in your neck, where does it do then?
S I goes down into your heart and makes blood for your body.

I And then how does that make a person grow bigger?
S Because if you have more blood you would, the blood
would push yourself up and you keep on growing until your age, then you stop and die.

I Alrightee, lets see. Is this thing still, ya its still hanging in there (tape-recorder).

I8 Now suppose we were talking about the tree and we figured out that it needed water and what else?

S It needed soil and seed for the roots to come up and grow.

I Suppose a tree had alot of water and not much soil?

S The tree would just fall down because if you don't have soil the tree would not stand up and there would be no insides.

I What happens if it has plenty of soil and not very much water?

S the tree would die because some trees don't have alot of water and it turns brown and some branches fall off the tree. Branches help the tree give this little sort of like honey inside of the tree that the tree, without the honey, it won't be like a tree.

I And were do you think that honey comes from?

S It comes from the water because once the water comes into a tree it starts like a maple syrup.

I So which do you think is more important for the tree, the water or the soil?

S The soil and the water.

I8 What about the person, we were saying a person needs exercise and what else?

S Food and water.

I Suppose a person had alot of exercise and food but no water?

S He would die off from thirst.

I Suppose he had enough water and did alot of exercise but didn't have any food, what would we end up with then?

S He would starve and get skinnier in his bones and everything.

I And suppose he had lots of food and lots of water but no exercise, what would happen then?

S Well then he will get fat and his stomach would hurt and then his mother would ask him to get some exercise.

I9 Suppose when we are looking at a seed of a tree, how do you think it knows it is time to start growing?

S When a tree starts growing it is the time it gets buried, and 2 days later a root forms on the bottom, about 15 months later there would be so many roots that the tree would know to start growing for the forest.

I Do you think the main thing that gets a tree growing is putting it in the soil?

S Yes.

I Is that the only thing?

S If the tree is not in the soil it won't grow, because
if a tree is outside of the soil, it will fall down.

END TAPE 4.2  (399-719)
BEGIN TAPE 5.1

I We were talking about how things know it is time to start to grow and you were telling me that the seed knows its time to grow ....

S When the roots form in the soil, the seed grows into a tree because when a seed stores water in it, the seed would crack or move into, like, a tree.

I What about a baby, what do you think causes a baby to start growing?

S Its his mother when shes, like, when she starts like, to drop out like, and drop out and the form in there somehow gets fatter and fatter and then she'll know the time the baby is going to come.

I So when the baby is going to come, is that what causes it to start growing?

S Yes when like, if a girl was like married and walking down the street with her husband and in the middle of the way she starts to faint and then the man asks her what was going on and the girl would probably say I'll have a baby soon.

I Um hum...

S She will, the husband would get her to a hospital as soon as possible.

I Right, and that is how a baby knows it is time to start growing?

S Yes.

I Do you think a tree or a person ever stops growing? How about a tree, do you think a tree ever stops growing?

S I don't think a tree would stop growing because trees are bigger forms than it used to be at 18 years, like go for 19 or 20 years until the dinosaurs are reformed again and they will knock down some trees and there won't be any trees in the forest.

I I see, how do you think the dinosaurs will be reformed? When do you think that is coming?

S When its 1999 or 1998.

I What do you think will cause them to come back or be reformed, any ideas on that?

S In the rocks where they were buried, in the ground.

I When were they buried?

S One hundred years before anybody was born.

I And they were buried then by something?

S They died out because they ran out of food and probably water, and fought with each other.

I So trees will keep growing until such a time as the dinosaurs come back?

S Yes, that is right.

I Do you think people ever stop growing?
Yes I think when they are very old and they have beards and when its the time to stop they fall down and their hearts stop beating and the blood stops going through their veins.

So a person stops growing when he dies, but keeps growing until he dies?

He keeps growing until the time his heart stops beating and the blood stops going through.

And what happens when that happens?

People put them in the coffin, bury them, and make a sign with whoever's name that died.

Alright, so then a person....

keeps growing until their heart stops and then they die.

Let me ask you a question. Suppose you and I were in a room together, say we were going to throw a party, and we invited people that were all born on January the 15th, 1960, so they were all born on the same day. So that means they would all be the same age when they came to our party, and we lined them all up against a wall, do you think they would all be the same size?

No, I don't think they would all be the same size because some of them might go to sports and some might go somewhere else like a lesson or in the orchestra and some people might not even work and might just stay their own size.

So if we looked at that room do you think people would be different sizes because they do different things, what do these things do?

Yes, like if you were playing basketball your hand gets bigger and you get taller and you can shoot more baskets in the basket.

Right, and if you don't play basketball....

You just, if you don't play basketball or do a sport you could still get bigger because you are doing something, not just sitting around, if they were born on the same year they would still be the same age but in different sizes.

I see, because they didn't ... different people grew ...

Did different things, that affects them growing or not growing.

And trees, do they grow to the same size?

I don't know about them.

Okay, last question, do you remember ever growing things at home or at school?

I grew a seed at home.

Have you ever had a puppy or a kitten or a hamster that you watched grow?

No, I haven't.

Have you ever seen a baby in your family?

No, I never had a baby in my family yet.
I  Ok, thats pretty well it.

END INTERVIEW (0-236)
APPENDIX B

SAMPLE INDIVIDUAL CONCEPTUAL INVENTORY - GROWTH

Interview: Pre-instruction interview
Subject: Philip
Grade: 3
Age: 9 years 1 month

1. The parameters of growth
The tree, dog, person, and rock are growing because they change and get bigger.

2. Sources and acquisition of requirements for growth

Plant
A tree needs a seed, roots, water, and soil to grow. Water picks up the soil and brings it in through the roots. The water then goes to the branches.

Animal
People need healthy food and exercise. People eat food and it goes to the neck.

3. Use of requirements for growth by the organism

Plant
The tree uses the water to make honey or syrup. The soil makes the rings in the tree. The rings get more each year, this is how the plant grows. The syrup is also important.

Animal
The food goes into your mouth and then in the neck it gets changed into 4 different food groups. It goes into your heart, and makes blood for the body. The blood pushes you up and makes you grow. The stuff you do not need goes out by veins.

4. Instigation of growth

Plant
The tree starts as a seed which starts growing at the time it gets buried. The seed stores water and cracks, and a root forms.
Animal

The baby gets fatter and fatter in the mother. The mother knows the time the baby is going to come. Then it grows.

5. Cessation of growth

Plant

Trees will not stop growing until the time that the dinosaurs return and knock them down.

Animal

People stop growing when they get old and their heart stops, then they die. People grow to different sizes because some exercise their bodies or work and other do not.

6. (Cell concept only)

7. (Cell concept only)

8. Experience with growth of living things

I grew a seed at home, thats all.
APPENDIX C
SAMPLE TRANSCRIPTION - THE CELL INTERVIEW

Interview: Post-instruction interview
Subject: Tracy
Grade: 10
Age: 15 years 5 months

Key: I# = Question posed by the investigator, (#) indicates interview question number where appropriate
S = Response or comments by the subject

I1 First off I would like you to have a look at these two drawings here and tell me what you think is going on in them?
S Growth
I OK, anything you want to elaborate on?
S The cells are dividing and that makes more cells, that is growth.
I What are the sort of general things you look at in organisms to see whether they are growing or not?
S Well, like measurement and that kind of thing.
I Anything else?
S I don't know.
I How about an organism you were not familiar with, like an ant and you were asked as part of a project to figure out whether this thing was an adult or a juvenile?
S I would compare it to other ones.
I So size would be a characteristic?
S Yes.
I2 Plants, in general, some questions. What do you think are the most important things a plant needs in order to grow?
S Water by the roots and sun through the leaves.
I Is that it?
S Yes.
I3 How are those two things used do you think to cause a physical increase in the size of the plant?
S I am not really sure.
I4 Plants, what do they start as?
S Seeds, they come from other seeds.
I How are they produced?
S They come off of, like in dandelions, the little seeds on the plant go flying around. The parent produces the offspring that way.
I If I were to get some sunflower seeds from a corner grocery and we put them in soil, watered them, gave them light, would they grow?
S No because they are cooked.
What if we get pea seeds from a plant store and planted those, would they grow?
Yes, because that is what they are for.
What is the difference between the two, what does the cooking do to a seed?
It kills the chemicals inside.
If I emptied a pack of pea seeds on the table in front of you and asked you to describe these, are these things alive, dead, non-living, or something else?
They are non-living because they have to be put under the right conditions.
What happens inside a seed to go from non-living to a living thing?
Growth.
But if it is non-living, it is not alive?
It will grow if you put it in water.
But before you do anything to it, like carrying it around in its package, it's not alive then?
No, it's not really dead, it's kind of neutral.
What's going on inside?
There are cells in it, they are dormant.
Do you think trees ever stop growing?
Yes, just like humans, they do.
Before they die?
Yes.
So a tree could grow 100 years and go on to live another 300?
Uh huh (Affirmative).
What causes a tree to stop growing?
Well, the cells stop dividing.
How would they know?
They would just stop, they just, the cells stop dividing and the growth would stop.
And why do you think they would stop?
I do not know.
Any ideas?
Once they reach a certain height or something, they, how do you explain it, they have to stop growing or the tree will die because there are no nutrients getting to the tree.
You think the height might be limited by the amount of food the thing can take in?
Yes.
How about people. What do you think are the important things that a person needs to grow?
Food, liquids, like water, air, and just healthy conditions.
Same sort of question regarding people as with the plants, how do you think that those things contribute to the physical increase in the size of a person?
Because they provide nutrients to the cells so that they can divide and grow.
I What form do those nutrients take?
S Vitamins.
I How does the system extract vitamins from things like a Big Mac?
S It goes through your system, it takes out what it needs and discards the rest.
I But how does it take out what it needs, do you think?
S It absorbs it.
I Any ideas about how it gets to the different parts of your body?
S No.
I8 How about the origin of a person? A tree starts as a seed, what does a person start as?
S An embryo, a baby.
I What about before that? Does it have a form before that?
S As an egg, that becomes fertilized.
I Does that become a full grown and completely developed person?
S Yes, but not right away.
I What happens to that small fertilized egg in order to eventually develop into a person?
S It grows because it is given food from the mother, it just grows inside the womb.
I How does it know how to develop into a person?
S It doesn't know how.
I10 In nearly all cases doesn't it have two eyes, two arms, two legs, how is that information packed in the cell?
S I do not know.
I Do you know what happens to that cell to get all the cells that make up the person?
S They divide.
I So they all divide from that one first one?
S Yes.
I Do you know the name of the process of that division?
S Mitosis.
I Are you sure of that?
S Yes, we learned meiosis and mitosis.
I Have you ever heard the definition of mitosis as follows: the production of two identical daughter cells from one parent cell?
S Yes. And meiosis, it goes through mitosis twice.
I Yes, lets stick to mitosis for a sec, o'kay, the production of two two identical daughter cells from one parent cell, is that correct?
S Yes.
I Now, a person develops from that single fertilized egg into a full blown person by what process?
S Well, mitosis, it sounds right and seems right to me.
I14 Well, if mitosis is only producing identical daughter cells, then how by mitosis do you think can you get liver and heart and kidney and eyes, etc, etc.
I do not know.

Have you ever thought about that problem?

Yes I have but I do not know the answer. I do not think we learned it.

Would you think the definition is wrong?

The definition of mitosis?

Yes, as the production of two identical daughter cells from one parent cell.

It could be.

Would you question it if you saw it in the textbook?

Yes, I think its kind of off, a bit too in depth for just grade 10 general science.

The process of mitosis?

No, how you could question, like, questioning.

But if you learned that this is what mitosis is by definition and then you also learned that a person develops everything by mitosis, you should end up with a big round blob...

Yes, but you don't.

What about a person, do you think a person ever stops growing?

Most of it does, like hair grows, but not height.

What do you think determines the height that a person becomes?

No, it just stops, the cells stop dividing.

I would like you to have a look through the microscope here, o'kay, tell me what you think that thing is. If its not in focus, use the bottom knob there.

Its a cell.

What kind of cell, any idea?

Um, a plant cell.

What makes you think it is a plant cell, anything in particular?

Oh, we did this in science, it looked like that.

What about it makes you say it is a plant and not an animal?

It seems so ... um ... like in line, sort of thing, thats all.

Do you think cells have anything to do with the process that is going on in this drawing?

I think so, they are growing, they are making more.

Do you think the only way something grows is by making more cells?

Yes, everything is made up of cells.

Are you sure all living things are made up of cells?

Yes.

There is no parts of you that aren't made up of cells?

No.

How about other organisms? Do you think plants are made completely of cells?

Yes.

How about the bark? When you cut it open....
S It doesn't seem like it would, that is what I am thinking about, that is the only reason I would doubt it, because humans are all made of cells, that's ok, but then you compare humans to bark, then it seems like .... its still cells though.

I15 I have a photograph here, any idea of what that might be?

S It looks like that one (points at microscope).

I OK, do you think there's anything in the photograph that has anything to do with what's going on here (the drawing)?

S I think that (the photograph) is inside the tree.

I Anything more you can tell me about what's going on in the photograph? Anything you recognize there?

S ...(pause)... these are dividing, these guys.

I The ones under B there?

S Yes, these are the stages, of mitosis, yes, I know those ...(pause)...

I14a A question a little of topic, I think I am going to pick up the pen, so I pick up the pen, and put it back down, in that what I just did, do you think that cells are involved in that act?

S No, except your brain is made of cells.

I People often say when you do something like that, your brain sends a message to your arm or hand to pick the thing up, what do you mean by the word message?

S It tells your arm to do that, I think that's a bit slow, I do things without thinking, like moving or like if I am nervous or something, I tap my toe, I don't know I am doing it, so I don't see how that could be true.

I So you don't think those kind of things would be under control of the brain?

S Ya, but for sending a message, I don't think that is true. You can sit here and think "I should go to the library" and then go do it, your brain doesn't say I'll go to the library.

I But with physical things can you make your brain tell your arm to do things?

S Yes.

I What actually is going on in your arm when you are moving, have you ever thought about what is actually making it do that?

S I've thought about that but I don't know.

I18 With cells, do you have any ideas about what controls how cells work?

S Parts of the cell are for different things. The parts of the cell form for different uses, that's all.

I19 How about people's life spans? Some people live to be be 120 but the average is about 80, dogs also have a life span, and there seems to be an end to it, what do you think causes that end limit to be set?

S Their bodies begin to deteriorate, it doesn't work so
I Do you think that is the same for all living things?
S Yes, unless there are other things that are killing it, like a plant you can kill, like it will die by itself, right, eventually, but you can kill it, like don't give it any water.
I Ok, I'm going to ask you about two topics or concepts. What I would like is your idea of what these two words mean. Not necessarily the textbook definition. Mitosis and meiosis, what do they mean to you?
S Cell division.
I Both of them?
S Yes, actually both of them divide.
I Is there a difference?
S Meiosis goes through mitosis twice, it produces more, like more cells come out of it. There is more phases in meiosis.
I Do you know what the difference is in terms of the end result of the two?
S Well yes, it starts out like in this picture, it starts out as one and then it ends out as two.
I That's mitosis?
S Yes.
I And what about meiosis, is there a difference in what you get at the end?
S In meiosis this (the cell in the picture) will get you two new ones and then those two split into two more.
I Anything else you can think of that is different between the two?
S No.
I Do they both occur in plants and animals?
S ... pause ... I think so.
I Do you remember ever having taken growth as a subject, not a subject, but as a unit in school, all the way back to when you were in elementary school?
S Growth, I remember doing experiments, but we didn't really study why things grow, only how to make them grow.
I Do you remember experiments where you had a bunch of them in the dark and a bunch of them in the light?
S Yes.
I Do you remember what happened to the ones in the dark?
S They did grow, at least mine did, we did that in grade 7.
I What does that make you think about statements people make that plants need light to grow?
S I think they are actually healthier if they have light, its just something like, its like you don't, its not really, you don't have to wash your hair, but its healthier if you do. Thats the way I see it, it just helps.
I How about experiences with growth normally, do you,
have you raised plants of your own, raised pets...
S  Yeh.
I  Baby brother or sister or cousin or someone you have
   seen grow from a baby on upward?
S  Uh Huh (affirmative).
I  Ok, basically that is all the questions I have got for
   you.

END INTERVIEW (0-420)
APPENDIX D
SAMPLE INDIVIDUAL CONCEPTUAL INVENTORY - THE CELL

Interview: Post-instruction interview
Subject: Tracy
Grade: 10
Age: 15 years 5 months

1. The parameters of growth

The tree and person are growing because their cells divide and make more cells. Size increases with growth.

2. Sources and acquisition of requirements for growth

Plant
Water enters by the roots and sunlight through the leaves.

Animal
A person needs food, liquids like water, air, and healthy conditions.

3. Use of requirements for growth by the organism

Plant
I do not know.

Animal
The food and liquids go into your system, nutrients in the form of vitamins are absorbed and it discards the rest. The nutrients get to the cells so that the cells can divide and grow.

4. Instigation of growth

Plant
Seeds come from parent plants. The seed is non-living and the cells are dormant. It will grow if you put it in water.

Animal
An egg that becomes fertilized becomes an embryo, a
baby. It grows because it is given food from the mother, it grows inside the womb.

5. Cessation of growth

Plant

Trees stop growing before they die. The cells stop dividing and the growth stops.

Animal

Humans stop growing before they die. The cells stop dividing.

6. The cell as the basic structure of organisms

Differentiation

A baby develops in the womb from a fertilized egg through the division of cells. The process is mitosis and I do not know where the different parts of the body come from.

Cell identification and relation to growth

This is a plant cell because it seems in line. Everything living is made up of cells. The cells are growing, they are making more.

Cell interaction with body functions

The brain is made up of cells. I do not know how it moves your arm.

7. The structure and function of the cell

Identification of cell reproduction and relation to growth

It looks like a plant cell inside a tree. Cells are dividing and the stages of mitosis are there.

Cell control and metabolism

Parts of the cell are for different things.

Mitosis and meiosis

Both are cell division. Mitosis starts out as one and ends out as two. Meiosis will get you new ones and then those two split into more. Meiosis goes through mitosis
twice, more cells come out of it. There are more phases in meiosis.

8. Experience with growth of living things

I remember doing experiments, we didn't study why things grow, only how to make them grow. The plants I grew in the dark did grow. Plants are healthier if they have light. I have raised plants, pets and watched a baby grow.