CASE STUDIES IN CONCEPTUAL CHANGE: THE INFLUENCE OF PRECONCEPTIONS AND ASPECTS OF THE TASK ENVIRONMENT

by

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ABSTRACT

CASE STUDIES IN CONCEPTUAL CHANGE: THE INFLUENCE OF PRECONCEPTIONS AND ASPECTS OF THE TASK ENVIRONMENT

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The motivation for this study is reflected in the growing concerns that much current instruction in science is not working in a fundamental sense. Students learning scientific concepts experience different patterns of conceptual development, resulting in qualitatively different conceptions. Many students do not seem to develop a functional understanding of the science concepts which they study.

Prior studies have focused upon the 'static' views of student conceptions (i.e., student conceptions at a point in time, prior to and following instruction), and have not examined the 'dynamics' of conceptual change over time. The key contribution of this study has been the design and implementation of a unique data collection system and techniques for data analysis which give a researcher the capability to explore the dynamics of conceptual change. In an effort to see if this methodology could be used to describe the parameters and patterns of conceptual change, a study was conducted aimed at gaining insights into the problems students have in learning scientific concepts.

An important feature of this study was the combined use of a group administered instrument, classroom observation and clinical interviews to gather data for constructing representations of student conceptions. This

study utilized a population of 22 fifth grade children, four of whom were selected, based upon their unique and interesting pre-instruction conceptual frameworks, for more intensive study (e.g., focused observation and clinical interviews).

The group administered instrument utilized a multiple-choice instrument intended to provide information necessary to "model mental (e.g., cognitive) structures", a process referred to in this study as psychomodeling. The observation of actual instruction provided a detailed representation of the milieu in which instruction occurred and assisted in the determination of those experiences which may have influenced the identified changes. Clinical interviews were used, as an in-depth method, to provide a controlled situational context in an effort to infer conceptual framework (i.e., for ascertaining cognitive structure) as well as follow it through the learning experiences.

A two phased data analysis process was aimed at organizing the data base for the effective translation of relevant observational and quantitative information into interpretable patterns. The purpose of the Phase I analyses was to identify the major changes that occurred in students' conceptions, the period of time during which they occurred, and the specific segment of instruction during which students encountered information directly related to the change.

Initially, the changes identified in Phase I were noted for each of the four target students. However, based on the voluminous amounts of data collected during twelve hours of observation over a period of ten weeks, only one student was selected for comprehensive analysis. Thus, this was a case study of an individual student's attempt to make sense of encounters with physical phenomena during a sequence of learning experiences concerning photosynthesis.

The results of the Phase I analyses were then used to guide the Phase II analyses where the transcripts of clinical interviews and relevant portions of lessons were used as primary data sources. The results provided an organizing framework which assisted in the description of important classroom, teacher, and student characteristics which could be used to describe relevant patterns and reveal the dynamics of conceptual change over time.

The results of this study demonstrated that the system for data collection and methods for analysis developed for this research effort were capable of revealing the patterns necessary to investigate the dynamics of conceptual change. It has provided insights concerning the nature of conceptual change and the reasons for the difficulties encountered in teaching for conceptual change.

The findings which evolved from the use of this comprehensive methodology suggest that matching instruction to the conceptual ecology of the students is both essential and difficult. The instructional materials must provide the teacher with not only an adequate strategy for promoting conceptual change, but also an understanding of the purpose of each specific learning activity. In addition, the importance and characteristics of misconceptions should be explored along with the development of improved patterns of planning and classroom teaching strategies (e.g., discussion skills) which enable the teacher to recognize student misconceptions from the responses they offer and to initiate strategies which will influence change.

DEDICATION

To my children

Jessica Dawn and Benjamin Matthew

for whom I embarked upon the road to this achievement,
and for whom I hope the sacrifices were not too great,

and to my mother

Madeline E. Lott

who did not see me complete the task.

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CHAPTER 1

PROBLEM OVERVIEW

Students learning science concepts experience different patterns of conceptual development, resulting in qualitatively different conceptions. Many students do not seem to develop a functional understanding of the science concepts which they study. The view that preinstructional knowledge will persist despite instruction has been supported by research in physical science instruction (Champagne, Klopfer, and Anderson, 1980; Gunstone and White, 1981; Leboutet-Barrell, 1976; McCloskey, Caramazza, and Green, 1980; Terry, Jones, and Hurford, 1985; Trowbridge and McDermott, 1980), and more recently by research in biological science instruction (Roth, Smith, and Anderson, 1983). Any effort to determine the factors which account for the differentiated degrees of cognitive competence should involve a study of the changes in students' conceptual frameworks as they learn scientific concepts (Berkheimer, 1978; Brown, 1982).

This chapter is intended to provide a statement of the problem, an overview of the study, the objectives, the assumptions and limitations which guided its design and conduct, and the potential value for curriculum and teaching.

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Problem Statement

The motivation for this study is reflected in the growing concerns that much current instruction in science is not working in a fundamental sense. That is, many students develop inaccurate conceptual frameworks as the result of their instructional encounters. Clement (1982) found that only thirty percent of the students enrolled in engineering had an understanding of Newton's laws following a two semester sequence in physics. Champagne, Klopfer, and Gunstone (1982) have argued that "the influence of the students' conceptions is to inhibit their understanding or distort their observations and interpretations of experiments." The naive conceptions which the student brings to the educational setting prior to instruction has an inhibiting effect on learning.

There have been many studies which have described the naive conceptions that students hold and the tendency for such conceptions to persist despite instruction. A few studies have examined in detail the instruction which apparently fails to bring about the intended learning. Eaton, Anderson, and Smith (1984) suggest, as the result of the Planning and Teaching Intermediate Science Study, that students have difficulty learning because their misconceptions are not adequately dealt with during instruction. Realizing the influence of misconceptions brought by students to the educational setting, Minstrell (1984) implemented an instructional strategy which took into account common student misconceptions. This was found to result in a significant improvement in learning.

However, these and other studies have focused upon the 'static' views of student conceptions (i.e., student conceptions at a point in time, prior to and following instruction), and have not examined the 'dynamics' of conceptual change over time. In addition, research has taken a global view of conceptual change (i.e., classes of students) rather than exploring changes on the part of an individual.

It is believed that the process of conceptual change is directly related to the actual educational process occurring at a given time and must be seen in that context. Conceptual change involves a change in the conceptual framework of the student through the action of internal mental capabilities during involvement in learning tasks. Moreover, Posner, Strike, Hewson, and Gertzog (1982) suggest that "whenever the learner encounters a new phenomenon, he must rely on his current concepts to organize his investigation."

Thus, there is a need to look at the changes which actually do occur and attempt to identify the factors which may account for them. While there has been a growing awareness of the problem and relevant theoretical developments, there is a need for studies of actual changes by an individual and the instruction which influenced them (Driver and Erickson, 1983).

The key contribution of this study has been the design and implementation of a unique data collection system and techniques for data analysis which give a researcher the capability to explore the dynamics of conceptual change. In an effort to see if this methodology could be used to describe the parameters and patterns of conceptual change, a study was conducted aimed at gaining insights into the problems students have in learning scientific concepts.

Study Overview

The unit selected to provide the context within which this study examined conceptual change was the 5th grade unit entitled "Producers" of SCIIS Communities as revised by Smith, Anderson, and Berkheimer (1981). Thus, this was a study of the cognitive structure and organization of complex scientific knowledge concerning photosynthesis and its change in structure during learning experiences. The unique aspect of this study is that it uses an integrated qualitative and quantitative research design which includes the intensive analysis of classroom interaction, the combination of group and individual analysis, and a focus on the instructional experiences of individual students.

An important feature of the methodology used for this study was the combined use of a group administered instrument, classroom observation and clinical interviews to gather data for constructing representations of student conceptions. This study utilized a population of 22 fifth grade children, four of whom were selected, based upon their unique and interesting pre-instruction conceptual frameworks, for more intensive study (e.g., focused observation and clinical interviews).

The group administered instrument utilized a multiple-choice instrument intended to provide information necessary to 'model mental (e.g., cognitive) structures,' a process referred to in this study as psychomodeling. Moreover, there is the use of an intensive analysis of actual instruction including both verbal and nonverbal aspects of individual student's instructional experience. This observation of actual instruction provided a detailed representation of the milieu in which instruction occurred and assisted in the determination of those experiences which may have influenced the identified changes. Clinical interviews were used to provide a controlled situational context in an effort to infer conceptual framework as well as follow it through the learning experiences.

The approach involved the identification of changes in a student's inferred conceptual framework in an effort to develop an understanding of conceptual change. This was accomplished through the use of psychomodeling, observational, and clinical interview methods to collect data necessary to formulate sequential representations of a conceptual framework, which could then in turn be used to examine the patterns of conceptual change. A schematic representation of this procedure is shown in Figure 1. The curricular unit provided the task environment for observations, the focal point for clinical interviews, and the propositional knowledge for psychomodeling instrumentation.

A two phased data analysis process was aimed at organizing the data base for the effective translation of relevant observational and quantitative information into interpretable patterns. The purpose of the Phase I analysis was to identify the major changes that occurred in students' conceptions, the period of time during which they occurred, and the specific segment of instruction during which students encountered information directly related to the change.

Initially, the changes indentified in Phase I were noted for each of the four target students. However, based on the voluminous amounts of data collected during twelve hours of observation over a period of ten weeks, only one student was selected for comprehensive analysis. Thus, this was a case study of an individual student's attempt to make sense of encounters with physical phenomena during a sequence of learning experiences concerning photosynthesis.

The results of the Phase I analysis was then used to guide the Phase II analysis where the transcripts of clinical interviews and relevant portions of lessons were used as primary data sources. The results provided an organizing framework which assisted in the description of

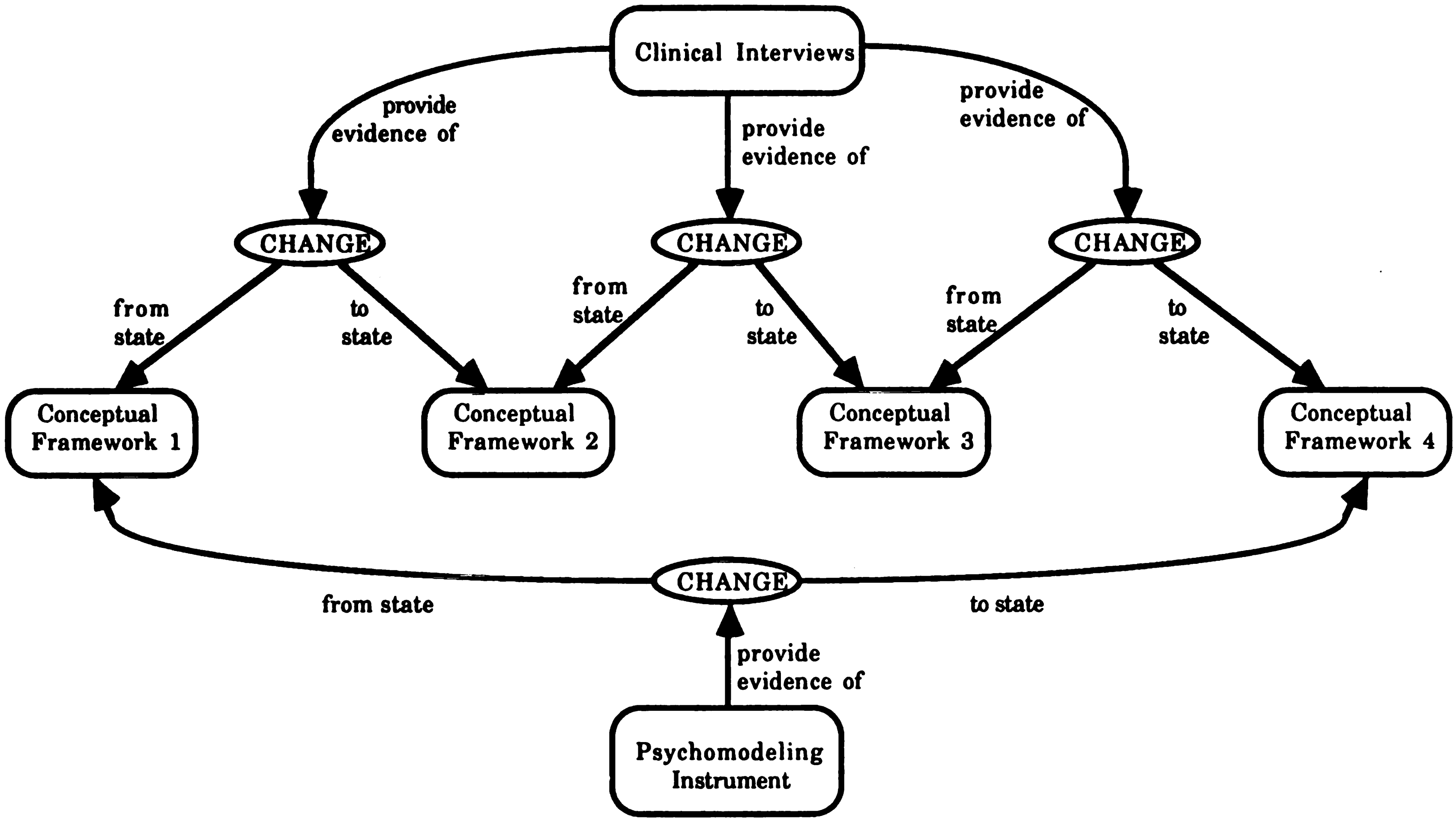


FIGURE 1. Procedure for Inferring Conceptual Change. (Schematic diagram of conceptual framework change as inferred over a period of time. Classroom observation will provide a representation of the context within which the conceptual change occurred.)

important classroom, teacher and student characteristics which could be used to describe relevant patterns and reveal the dynamics of conceptual change over time.

Purpose

Descriptive

As a descriptive study the intent of this research was to investigate the empirical nature of conceptual change. The patterns and parameters thus exposed can be used along with the current theoretical foundations of conceptual change (see Driver and Easley, 1978; Hewson, 1981; Nussbaum and Novick, 1982; Posner, Strike, Hewson, and Gertzog, 1982; and Toulmin, 1972) to formulate issues for further research, as well as recommendations for curriculum development and teacher education based upon the characteristics of student conceptions and the nature of conceptual change.

The study was descriptive and aimed primarily at generating hypotheses. Moreover, the purpose of the study was to describe the parameters and patterns of conceptual change in an effort to gain insight into the problems students have in learning abstract concepts. This was an exploratory study aimed at developing the foundation for research studies of the process by which individuals "come to know," or to understand the world. Discovering patterns of conceptual change will provide the necessary framework from which an explanation of the process of conceptual change can be sought through additional research efforts.

Questions

This research opens new territory with its effort to follow the changes in these pre-conceptions during the student involvement in a science-oriented task environment. The question of interest in this study is:

- What are the patterns and regularities in instances where students change their preconceptions toward more scientific ones having greater complexity and generality?

In an effort to resolve this question the following points have been explored:

- How do students respond to incongruities between their preconceptions and the scientific content they encounter?
- What changes occur in students' conceptions as they experience instruction?
- How do students' preconceptions influence their interpretation of instructional content?
- What features of instruction influence the occurrence and direction of changes in students' conceptions?

The effort to resolve these questions has involved the application of techniques from cognitive science to the exploration of phenomena in a science education setting.

Assumptions and Limitations

The theoretical framework which guided the design and conduct of this research represents a set of assumptions of which the reader should be aware. These assumptions concern the nature of case studies and the generalizability of the results, as well as the process for inferring cognitive structure. The inherent limitations are two-fold; they concern what this research is a case(s) of and what it is not a case(s) of.

Case Studies and Generalizability

The improvement of the teaching and learning process can be facilitated by seeking, through the application of creative imagination, a less limited perspective of the classroom environment and the actions which occur within it. Through previous research efforts (Nussbaum and Novick, 1982; Sendelbach, 1980; Smith and Anderson, 1983) it has been documented that by observing the classroom situation it is possible to find patterns which lead to greater insights concerning the relationships which influence learning.

A guiding assumption of this research is that behavior results from the interaction of innate information processing capacities and learning experiences. The key benefit of the case study approach is that it provides a deep understanding of classroom phenomena which results in a generalizability based upon the increased ability to make distinctions and recognize parallelism in experiences; what Stake (1978) refers to as "naturalistic generalizability." The goal of this form of research is to impose some order on the perceptions of what is happening and through these efforts increase the explanatory power of the descriptions of classroom occurrences.

This view of generalizability ensues from the supposition that, as the principle means of the evolution of knowledge, the notion of theory appraisal which employs the premises of the reduction of uncertainty or hypothesis testing does not adequately model our search for reality. The argument for this view revolves around the belief that reality is far too rich and varied to be adequately reflected in a logical theory of probability involving the degree of confirmation. Hanna (1980) submits that the intent of inferential inquiry is to discover evidence and formulate theories which increase our information about natural or sociological phenomena. This increase of information content results in a conceptual framework which is less limited in its ability to describe and explain phenomena as a result of insights which lead to the identification of more comprehensive patterns which support more restrictive distinctions.

Thus, the important factor in the growth of knowledge through inferential reasoning is the information content of our representation of the world. The generalizability of this research can be found in the growth of knowledge which it generates. As Geertz (1983) has argued:

> The move of social theory toward seeing social action as configuring meaning and conveying it, ..., opens up a range of possibilities for explaining why we do the things we do in the way that we do them far wider than that offered by the pulls and pushes imagery of more standard views. (p. 233)

Since the conveying of meaning through information exchange is an important aspect of all cognitive systems we will reject the support paradigm and focus our attention on the meaning discerned from observations as the parameter of interest for appraising scientific theories. The generalizability of social science research is viewed to come from the use of its observations to falsify theories as opposed to the traditional methodology of trying to arrive at theories on the basis of an inductive inference from observations.

The conduct of this research recognizes that showing a theory to be false is immensely more effective in the appraisal of theories. Moreover, there is a recognition that the principal approach to increasing the validity of case study results is by triangulation in an effort to substantiate the perceived constancy of the observed phenomena. Triangulation will occur, in terms of this case study, across multiple studies as other researchers examine the issues of conceptual change manifest in the data. Campbell (1975), as part of a discussion concerning degrees of freedom in qualitative research, argues that there are "great gains in understanding which such multiple ethnographer studies would introduce" (p. 190). This study will, in triangulation with the results of other studies, enhance our understanding of how changes in children's concepts are influenced by their experiences.

Thus, a case study can be considered valid if it gives a well-grounded and useful representation of the case in a specific setting which lends itself to comparative analysis. The more alternatives a semantic representation admits of, the more probable it is; while the more alternatives a semantic representation excludes, the more informative it is. This view of the research process which has provided a framework within which to conduct this study, while accepting the value of internal indices which provide convergent evidence, seeks a more enlightening perspective and argues that the assessment of generalizability goes beyond the analysis of one case study. Miles and Huberman (1984) argue in their treatise on qualitative data analysis that support for case study findings is accumulated "by showing that independent measures (e.g., other case studies) of it agree with it or, at least, don't contradict it" (p. 234).

Especially in the instance of case studies, it is most appropriate to begin with the formulation of descriptive theories before one attempts to develop theories with predictive, or explanatory power. It is therefore more appropriate to look at particular research data from case studies as having a measure of descriptive power when considering its generalizability.

Those who conduct qualitative (i.e., naturalistic) research approach the search for universals differently than do those who conduct positivist research on teaching. Ethnographic research is based upon several assumptions regarding the educational process. First among these is that an important source of explanation for classroom phenomena is the social context in which teaching and learning occur. The members of the observed situation are regarded as knowledgeable beings whose behavior is purposeful and meaningful in this context. It is important to note that the types of thought processes exhibited in classrooms appear to be very dependent upon the nature of the cognitive task focused upon. Thus, this research will take into consideration the importance of the environmental factors influencing instruction, and the process of social interaction.

Naturalistic researchers, in their quest to interpret their experiences and seek insights for improving the teaching-learning process, are more cautious in their assumptions than are those who apply the positivistic paradigm to the study of teaching (Lott, 1981b). Given these assumptions about the state of nature in social life that interpretive researchers make, they pursue insights which may transcend the site of the research. Concrete universals are arrived at by studying a specific case in great detail and then comparing it with other cases studied in equally great detail.

Erickson (1986) argues that "the primary concern of interpretive research is particularizability, rather than generalizability" (p. 130). This view of the focus of research rests upon the belief that the goal of qualitative analysis is to reveal the multiple layers of universality. The task is to discover what is broadly universal, what generalizes to other similar situations, what is unique to the given situation. Each instance of a classroom is seen as its own unique system, which nonetheless displays universal properties of teaching.

Inferring Cognitive Structure

It is becoming generally accepted that understanding of classroom teaching and its effects on learning requires going beyond the description of observable behavior to the investigation of the meanings and antecedents of that behavior (Clark and Yinger, 1978). The learners are viewed as having certain prior knowledge, attitudes, and abilities which influence and are influenced by, classroom instruction resulting in particular learning outcomes for each student.

The relation between observed responses and claims about cognitive structure guided the process for inferring cognitive structure. It is thought that conceptual change is influenced by the context within which it occurs, thus a representation of the context will be attempted utilizing observational data to provide a description of the classroom milieu and the context of instruction. A student's conceptual framework will be inferred from data obtained as students explain scientific phenomena and develop and test hypotheses (see Figure 2).

Observed task performance was viewed as resulting from an application of an individual's knowledge and thus as providing a basis for inferences about the underlying knowledge. In keeping with contemporary cognitive psychology, as well as Piagetian views, we believe that learning involves an interaction between a student's prior knowledge and his or her current experience. This view suggests that it is important to know what the students' prior knowledge is and that students may end up with quite different knowledge as a result of apparently similar experiences. Thus, it is important to characterize students' knowledge, and not just quantify it. The approach used in this study was to develop models of student knowledge.

Case Studies of Conceptual Change

There were no instances of major conceptual changes to analyze. Rather there were several small changes (i.e., "conceptual capture" (Hewson, 1981)) and non-changes. The reason this is enlightening about the nature of conceptual change will be explained.

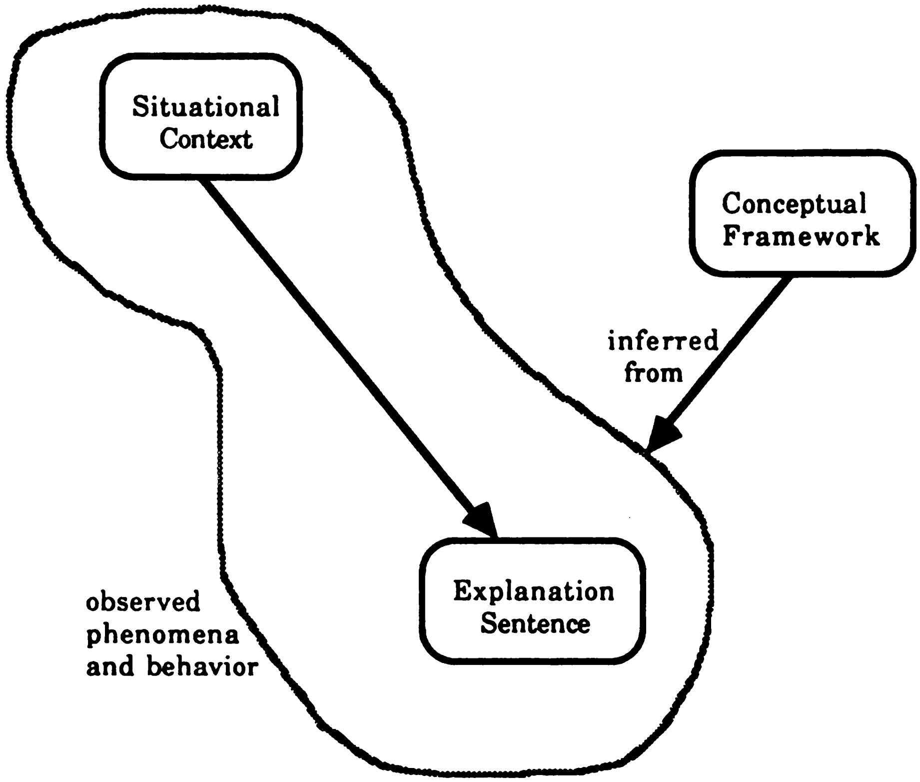


FIGURE 2. Inferring Cognitive Structure. (Using the explanation of phenomena and the representation of the situational context you can infer the conceptual framework for the student who gave the explanation.)

This is a case study of an individual student's attempt to make sense of encounters with physical phenomena during a sequence of learning experiences concerning photosynthesis. Representations of the subject's conceptual framework were used to reveal the dynamics over time. In an effort to expose relevant patterns and regularities within the sequence of learning experiences the actual instruction was observed so as to determine experiences which may have influenced the selected changes.

A major concern in the research is the effect of the instruction on student knowledge. In particular there was an interest in the extent to which students' knowledge comes to match that which the program materials identify as potential learning outcomes. This research can be viewed as attempting to describe and account for the patterns of student knowledge that result from instruction.

Seeing rather than measuring was the activity of this project. The interest was to seek representations of experience which could be used to illustrate issues of conceptual change. These issues were the central foci; guiding the analysis, organizing the understanding. This research was experience-oriented; what principally we hoped to see was not something to hold a ruler to. It consisted of intensive field observations and interviews as a means of recording differing images and meanings. The naturalistic orientation focused attention more to images and meanings than to properties and measurements; as such they were to form the conceptual structure for the work. The goal of this effort is to provide a knowledge base for addressing the problems identified through improved teacher education as well as curriculum development and revision.

Implications for Curriculum and Teaching

Reid (1978) has argued that research is needed to enable us to comprehend the nature of disciplinary knowledge, learners, teaching, and milieus such that this understanding can be infused into curriculum planning for schools. He contends that curricular decisions are concerned with what should be done and thus entail a value component which necessitates the justification through an ideational foundation. Through an understanding of the conceptual change process a determination can be made regarding how to address given goals or conceptual frameworks as part of the instructional sequence.

Analyzing the paths of conceptual change can lead to an understanding of the relationships between concept formation and the task environment which the students encounter in the classroom. The task environment is a concept which has been elaborated on by Newell and Simon (1972), and refers to an environment which is goal-oriented in the sense that there exists a task or problem to be encountered. The tasks (i.e., problems) which are of interest in this study involve student participation in experimental set-ups and corresponding key questions which were intended to guide the observation and interpretation of phenomena during a sequence of learning experiences concerning photosynthesis.

The importance of this relationship can be perceived in the lack of homogeneity in conceptions, as well as the existence of certain naive conceptions, prior to instruction. Individuals have different conceptions of subject matter and apprehend curricular tasks in various ways. It is therefore in the interest of curricular improvement that systematic research on the nature of conceptual change should be embarked upon through carefully designed studies of human intellectual functioning. The synthesis of such research can provide a framework within which curricular decisions can be articulated.

Since an important goal of science instruction is the modification of students' conceptions of natural and physical phenomena, it is important to understand the nature of such changes and the conditions under which they are most likely to occur. A study of the changes in students' conceptual frameworks as they learn scientific concepts can help to determine the factors that account for this variation. It is through an understanding of the process of conceptual change that appropriate learning experiences can be provided in an effort to support or enhance the development of conceptual frameworks. Through an attempt to determine the conditions which lead to and facilitate a successful conceptual change a theory of conceptual change may evolve.

CHAPTER 2

RESEARCH FOUNDATION

This chapter will review the previous research which provides background for this study, and the theoretical and methodological assumptions which guided the research. The previous research which is examined includes that concerned with children's conceptions, their misconceptions, and the growing knowledge base concerned with conceptual change in the educational setting. Theoretical assumptions are then identified in an effort to reveal the epistomological and methodological foundation for the study.

Research Review

This section deals with the extent to which this research builds upon previous research. This will involve an examination of current and past research efforts concerning children's conceptions, student's misconceptions, and conceptual change. The narrative will describe the way in which these studies have contributed ideas and direction to this study. Moreover, the section will provide an indication of the extent to which the study moves the field ahead in some significant manner.

Children's Conceptions

Prior to the work of such science educators as Gunstone and White (1981), Leboutet-Barrell (1976), Nussbaum and Novak (1976), Rowell and Dawson (1977), Viennot (1980) and Pines, et. al. (1978), much of the research on science learning utilized the assessment of the 'amount' known by students as represented by scores on norm or criterion-referenced tests. The specific knowledge an individual has, or the alternative conceptions that individual may use to interpret experience, have not been a focus of most previous research efforts. The interest in student learning outcomes has been on the results and not the patterns of conceptual change. In order to determine the patterns and parameters of conceptual change, an approach is necessary for inferring student conceptions.

The research by Smith (1980b) was aimed at developing methods for assessing and modeling students' knowledge of a given topic. The interest has been to determine the effect of instruction upon student conceptions through the process of investigating their match with the potential learning outcomes as identified by the program materials. The reliability of this approach in the development of psychomodeling instrumentation was investigated (Caldwell, 1980).

Methods for the assessment and modeling of student knowledge for a given topic were applied through the development and utilization of a multiple choice instrument for the "Oxygen-Carbon Dioxide Cycle" Unit of SCIS Ecosystems (Smith,1980b). The analysis of this unit for a prior study (Sendelbach, 1980) resulted in the identification of a set of propositions which the students should encounter through participation in the suggested activities. A subset of the propositions identified in the analysis were selected and used in the development of multiple choice items for the test which was intended to provide data relevant to declarative propositional knowledge. The techniques for quantitatively analyzing student responses were then formulated and applied (Smith, 1980a).

The development of the psychomodeling instrument was guided by a cognitive view of knowledge in which two kinds of knowledge are distinguished; propositional and procedural (Greeno, 1976), and their relation to student cognitive performance. An idividual's knowledge is viewed as consisting of integrated sets of propositions and procedures. The conception of propositional knowledge with which this research effort has dealt is that of interrelated statements having a truth value represented by conceptual networks (see Figure 3). A conceptual network is a representation of knowledge in which concepts are nodes connected by labeled, directional relations. Such a network provides a means by which the interrelations among propositions can be represented.

An important aspect of this developmental task (i.e., the formulation of a psychomodeling instrument) is the segmentation of the instructional unit in such detail that the propositional knowledge addressed can be used to develop items. Lucas and McConkie (1980) have encouraged this kind of an approach and have indicated that "the passage to which questions are to be related be segmented into units of sufficient detail for the user's needs, with each unit numbered for referential purposes" (p. 134).

The research by Lott (1980) indicated that more than the use of a psychomodeling instrument was needed to follow conceptual change. If a dynamic process such as conceptual change is to be descriptively investigated then the representations provided by the psychomodeling instrumentation must be supplemented. Sutton (1980) has argued that "any useful conceptualization of how a learner's thought is organized must include some picture of its dynamics as well as its statics" (p. 107). However, in order to have adequate data upon which to attempt to study patterns of conceptual change during student involvement within the task environment, one must be able to infer the conceptual framework between those points in time when an instrument is administered.

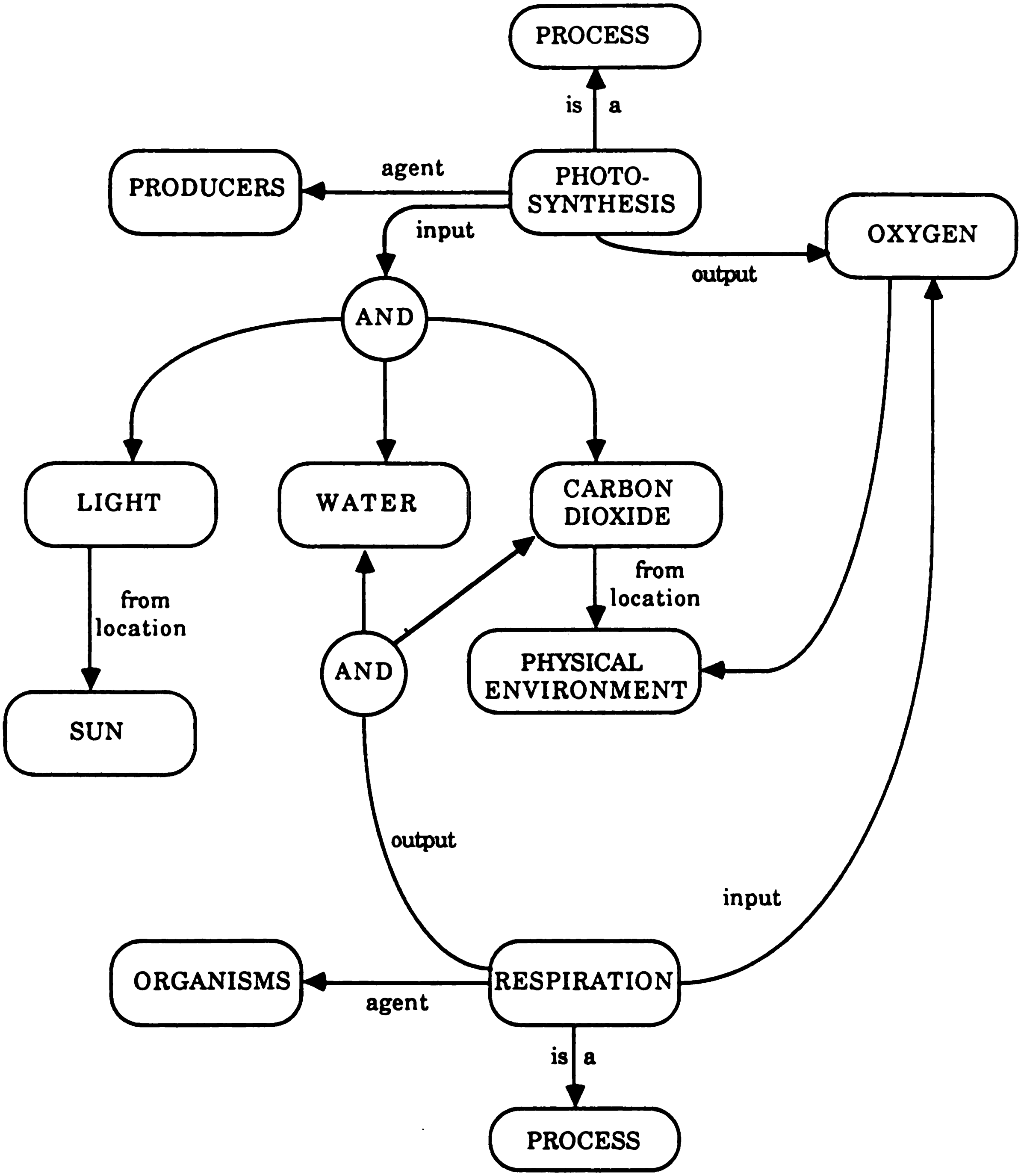


FIGURE 3. Conceptual Network Structure. (A means by which knowledge structures are represented by a labeled, connected network consisting of nodes interconnected by relations. Each relation indicates an association between two nodes, with the interpretation depending both on the label and on the direction in which the relation is traversed.)

In an effort to accommodate this need, the utilization of clinical interviews was included in the research design of this study. This approach has the potential for revealing a student's conceptual framework through the method of eliciting verbal explanations of scientific phenomena and thus providing an avenue through which a descriptive assessment of a student's conceptual framework can be formulated. Posner and Gertzog (1979) have suggested that the aim of the clinical interview is:

> ... 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 the perceived relationships among those conceptions (p. 2).

The clinical interview involves the use of a technique which provides the necessary data for the assessment of student conceptions.

This approach to the study of student's conceptions has been used by Pines, Novak, Posner and VanKirk (1978) and Posner and Gertzog (1979) in science education, and has been used by Erlwanger (1974) and Confrey (1980) in mathematics education. However, these studies have only been concerned with the 'statics' of student's conceptions, or if interested in conceptual change have only utilized undergraduate students as subjects. This study will utilize the clinical interview technique with intermediate school students in an effort to describe the patterns of conceptual change.

The observation of the context of classroom instruction will build upon the ethnographic research of Sendelbach (1980), the developmental work of Hollon, Anderson and Smith (1981), and the experiences of the Planning and Teaching Intermediate Science Study (Smith & Anderson, 1984).

Student Misconceptions

Recent reported research on student misconceptions in science and mathematics established that students generally possess conceptions about curricular topics before they begin to study them (Helm & Novak, 1983). Further, such preconceptions often persist despite instruction on scientific theories that contradict them. Discrepancies between the students' post-instruction conceptions and the scientific theories taught often represent important failures of instruction. The research suggests that preconceptions actively compete with scientific alternatives as organizing structures for students' experience of instruction and as explanations for their everyday experience.

Champagne, Klopfer and Gunstone (1982) point out in a review of the literature that physics learning studies demonstrate that students' pre-instructional world knowledge is often logically antagonistic to the principles of Newtonian mechanics taught in introductory physics. They suggest that students have descriptive and explanatory systems for scientific phenomena that develop before they experience formal study of the subject. These descriptive and explanatory systems differ in significant ways from those the students are expected to learn as the result of formal study.

Case studies in mathematics conducted by Erlwanger (1974) suggest that each child developes a conception which appears to function as a relatively stable, cohesive system of interrelated ideas, beliefs and views about mathematics. Discussions with the children revealed conceptions that were unanticipated and different from an adult view of mathematics. Driver and Erickson (1983) argue that students may develop conceptual structures as a result of instruction and other experiences which can be internally consistent and quite elaborate, but which do not necessarily relate to actual phenomena.

Cognitive science research has begun to yield research findings which reveal the misconceptions of students in varied subject matters. McCloskey, Caramazza and Green (1980) found that many students who have completed one or more physics courses fail to understand the most fundamental principles of mechanics. Their findings revealed that students do not merely lack such knowledge; they espouse "laws of motion" that are at variance with formal physical laws. They argued that little consideration has been given to the possibility that knowledge representations may frequently be at variance with physical reality. In another study, Doran (1972) investigated the occurrence of common misconceptions related to the kinetic theory of matter by 7-12 year old pupils. Za'rour (1975) in his study of science misconceptions among high school and university students in Lebanon isolated twenty common misconceptions in the areas of physics, earth science, chemistry and biology.

In addition to research which has attempted to describe student misconceptions there is evidence that these alternative conceptions are resistent to change. A study by Leboutet-Barrell (1976) indicates that high school and college students have misconceptions about force and motion which persist despite instruction. Moreover, these misconceptions were described as pre-Galilean. Champagne, Klopfer and Anderson (1980) found these effects of resistance to change particularly striking in the context of mechanics where prior to formal instruction young people and adults were found to have a conception of motion that is more Aristotelian than Newtonian. Other research findings by Gunstone and White (1981) showed that remnants of the Aristotelian conception persist with many "successful" physics students.

Children's underlying conceptions (referred to as "alternative frameworks" by Nussbaum and Novick (1982), "naive theories" by Eaton, Anderson and Smith (1984), and "misconceptions" by Anderson and Smith (1984)) have been found to influence their observable behavior. The case studies conducted by Erlwanger (1974) suggest that as children learn they develop their own conceptions of mathematics that influence their mathematical behavior and subsequent learning. Moreover, he reported that the teachers often misunderstood and misjudged the nature of the children's understanding and progress, and the adequacy of their learning experiences.

Champagne, Klopfer and Gunstone (1982) also contend that prior knowledge affects students' comprehension of science instruction. Students interpret instructional events (e.g., experiments and expository text) in the context of the conceptual scheme they currently hold, not the one that the experiments or the text are designed to convey. It is not the students' lack of prior knowledge which makes the learning of this topic so difficult, rather their conflicting knowledge.

Based upon the research which they have reviewed, Driver and Erickson (1983) argue that there is now growing interest in the notion that students do possess "invented ideas" based upon their interpretations of sensory impressions. Moreover, these "invented ideas" influence the ways in which they respond to and understand the disciplinary knowledge as presented in the classroom. In laying out a generative learning model, Osborne and Wittrock (1983) also argue that students "invent a model or explanation" which serves to organize the information obtained from an experiment or demonstration.

Considerable research has been done to identify student misconceptions. In a study of the mole concept, Duncan and Johnstone (1973) analysed the difficulties of 14-15 year old pupils who were following the Scottish alternative 0 grade syllabus in chemistry. They reported three areas of difficulty. Johnstone, MacDonald and Webb (1977), in a study with 16-18 years old chemistry students where they studied the misconceptions related to concepts in thermodynamics, reported that the results indicated 8 major misconceptions. In a study of high school and university students, Lebouter (1976) indentified commonly held misconceptions related to ideas of force and motion which persist despite instruction.

The variety of misconceptions and their persistence have been explored more thoroughly by Viennot (1974) who analysed attempts at solving dynamics problems by university physics students. The results indicate that certain pre-Galilean ideas persist. An earlier study by Kuethe (1963) found a class of questions about common astronomical or physical phenomena to which secondary school pupils, in spite of instruction in the sciences, gave a ready reply but often answered incorrectly. Brumby (1979) found that O-Level students in England persist in holding a Lamarckian conception of evolution despite a Darwinian instructional approach. Camamazza (1981) has reported that one third of a group of introductory college physics students persisted in misconceptions about the trajectory of objects emerging from a circular track, despite formal instruction in Newtonian mechanics. Norman and Clement (1981) have shown that many university students tenaciously cling to misconceptions about the nature of electric circuits.

The results of these and other studies indicate that traditional instruction does not facilitate an appropriate reconciliation of preinstructional knowledge with the content of instruction. Alternative conceptual systems are remarkably resistant to change by exposure to traditional instructional methods. Moreover, there appears to be evidence (Champagne, Klopfer and Gunstone, 1982; diSessa, 1982; Nussbaum and Novick, 1982; Siegler and Klahr, 1982) that these alternative conceptual systems are not facilitative to the learning process; they may actually inhibit conceptual change.

Often the influence of the students' conceptions is to inhibit their understanding or distort their observations and interpretations of experiments. Other research (Champagne, Klopfer and Anderson, 1980) demonstrates that the belief in the proposition is not readily changed by instruction, the prior knowledge having an inhibiting effect on learning. One important factor that may account for students' learning difficulties then, is the reluctance, or perhaps inability, of students to alter their present commitments in favour of the school-sanctioned interpretation.

Diagnosing a pupil's misconceptions appropriately is but the first step toward helping the pupil to replace his persistant preconceptions with the scientific conceptions. Nussbaum (1980) suggests that while there is a need to diagnose pupils' answers for possibly existing misconceptions, many difficulties encountered by students in comprehending and internalizing certain concepts would be avoided if teachers were better prepared to listen to their pupils, understand the nature of their misconceptions and, in turn, make constructive use of this knowledge on the pupil's behalf. Andersson (1980) has argued that discussions and experiments can increase the pupils' awareness of inconsistencies in their ways of reasoning and contribute to an attitude of searching for invariants and principles beyond what is specific.

Rowell and Dawson (1977) also explicitly considered common misconceptions when designing instruction concerned with floating and sinking bodies. Their findings indicate that despite efforts to refute misconceptions in instruction, some misconceptions persisted. In a study by Driver (1973), it was found that although alternative theoretical frameworks to explain observations were introduced to the students and used during the instruction, the counter-examples and conflicting evidence did not produce changes in students' thinking. As the results of these studies suggest, the use of counter examples may not be sufficient in itself to produce change in pupils' underlying conceptualizations.

The studies reported here are an indication of the existence of a problem; pupils develop misconceptions which can persist despite instruction. However, the development of a taxonomy of such misconceptions does not yield interpretive power. Not until the reasons for the misconceptions are understood will progress be made in instructional terms. McCloskey, Caramazza and Green (1980) have argued that educators in the sciences should not treat students as merely lacking the correct information. Instead, educators should take into account the fact that many students have strong preconceptions and misconceptions. When a student's naive beliefs are not addressed, instruction may only serve to provide the student with new terminology for expressing his erroneous beliefs.

<u>Conceptual Change</u>

The existence and persistence of students preconceptions implies that learning involves not simply the acquisition or formation of new concepts. It involves the modification of existing concepts or their replacement with appropriate alternatives (i.e., conceptual change) (Toulmin, 1972; Brown, 1977). The predominant instructional question that follows from this position is one of how to facilitate some sort of "conceptual change" in the learner.

While it can be argued that the goal of the instructional process is the facilitation of conceptual change, Posner, Strike, Hewson and Gertzog (1982) affirm that identifying misconceptions (i.e., alternative frameworks) and understanding some reasons for their persistence, falls short of developing a reasonable view of how a student's current ideas interact with new, incompatible ideas. Nussbaum and Novick (1982) have stated that studies of student alternative frameworks "demonstrate that in learning basic science concepts students are not passive absorbers of 'new knowledge', but rather active participants who must effect substantive changes in their preconceptions (p. 1)."

Whenever the learner encounters a new phenomenon, he or she must rely on his or her current concepts to organize his or her investigation. The childs' own commitments are likely to be highly significant in determining what they find initially plausible and, thus, in shaping their conceptual changes. This suggests to Posner, Strike, Hewson and Gertzog (1982) that it is important to find out just what epistemological commitments students have, if one wants to understand what they are likely to find initially plausible or implausible and more generally, to understand their processes of conceptual change. However, they point out that there has been no well-articulated theory explaining or describing the substantive dimensions of the process by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first.

Brown (1982) argues for seeking out potential models for understanding and promoting conceptual change in students. She recommends obtaining rich and detailed descriptions of the qualitative differences between students within a particular domain by observing learning actually taking place within a learner, or group of subjects, over time. It is her contention that most work on the assessment of conceptual frameworks has tended to focus on the 'snap-shot' model rather than a continuous monitoring model.

Hewson (1981) has advocated a theoretical perspective of conceptual change which articulates the conditions under which an individual holding a set of conceptions of natural phenomena, when confronted by new experiences will either keep his or her conceptions substantially unaltered in the process of incorporating these experiences, or have to replace them because of their inadequacy. A new conception C' could be rejected; or reconciled (i.e., incorporated) with C in a process referred to as conceptual capture; or there may be a conceptual exchange whereby C is replaced by C' because they are mutually irreconcilable. He suggests that if he or she holds a plausible alternative conception which contridicts that which is presented, the model indicates that the new material cannot be meaningfully incorporated because it is not plausible.

In addition to Hewson (1981), several other researchers have proposed models of conceptual change. Posner, Strike, Hewson and Gertzog (1982) propose four conditions that must be fulfilled if accommodation is likely to occur, that is, if students are to make changes in their central concepts. These include:

- There must be dissatisfaction with existing conceptions.
- A new conception must be intelligible.
- A new conception must be initially plausible.

- A new conception must appear fruitful (i.e., lead to new insights and discoveries).

Nussbaum and Novick (1982) on the other hand describe a general teaching strategy for use when significant accommodation is expected:

- First, exposure of students' alternative conceptions through their responses to an "exposing event".
- This is followed by sharpening student awareness of their own and other students' alternative conceptions through discussion and debate.
- Next, the creation of conceptual conflict by having the students attempt to explain a discrepant event.
- Finally, encouraging and guiding cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

In addition to the research which has focussed on identifying and documenting the conceptual frameworks used by students in classroom settings, another strand of research activity has examined the effect of intervention strategies on student frameworks. Champagne, Klopfer and Gunstone (1982) have applied the theory and empirical findings of cognitive psychology (mainly information processing theory) in making explicit an instructional design model for initiating cognitive change. They engaged students in Socratic-type dialogues so as to arrive at explicit, qualitative responses to a series of problem statements. The teacher then provided the expert's analysis of the problems and asked the students to analyze their own solutions in the light of the expert's solution. The assessment of the effectiveness of engaging uninstructed students in this type of Socratic instructional dialogue was based on a qualitative analysis of mechanics problems. They reported no appreciable differences being discerned between the pre- and post-instruction cognitive states.

Osborne and Wittrock (1983) have drawn extensively upon information processing psychology to develop a "generative learning model" which gives a general description of the processes a learner goes through in constructing new knowledge. This model suggests three teaching stages as necessary to promote conceptual change: first, students attention is focussed on a range of experiences relevant to the topic in order to familiarise them with the materials and the phenomena; second, students are encouraged to make their personal ideas public through discussion and debate so that these may be challenged; third, the accepted model is presented and students are encouraged to explore the utility of various models by applying them to familiar and novel problem solving tasks.

Another formal model of conceptual change has been elaborated by Posner, Strike, Hewson and Gertzog (1982). Drawing upon current work in the philosophy of science (Kuhn, 1970; Lakatos, 1970; and Toulmin, 1972) and information processing psychology (Norman and Rummelhart, 1975), they have distinguished between gradual, evolutionary changes and discontinuous, revolutionary changes in conceptual structure. The results they report for their intervention studies are in general very encouraging as they seem to be obtaining some success in bringing about significant conceptual changes for many of the students in the topic areas they have explored to date.

Nussbaum and Novick (1982) applied their model to the development and assessment of an instructional strategy promoting specific changes in sixth-grade students' conceptions of the nature of gases. The purpose of the study was to implement and make a qualitative assessment of a teaching strategy designed to promote conceptual change. They reported that the strategy was "highly efficient in creating cognitive challenge and motivation for learning," but "did not lead to the desired total conceptual change in all students (p. 17)." They concluded that:

> ... our findings may be interpreted to mean that a major conceptual change does not occur, even with good instruction, through revolution, but is by nature an evolutionary process. (p. 18).

Driver and Erickson (1983) stated that the results of the studies they reviewed on cognitive conflict were generally mixed. They concluded that while there did appear to be genuine shifts in some aspects of students' frameworks, there was also evidence of a number of student ideas which remained resistant to this type of instructional strategy.

Prior studies have usually furnished static pictures of student conceptions prior to and/or following instruction. In order to better understand what happens as students change their conceptions during instruction, it is necessary to study the process as it actually unfolds in the classroom during the course of instruction. While it is crucial to identify the range of alternative conceptions of different phenomena likely to be held by students, it is important to identify and address students' metaphysical commitments which are often implicit but serve to anchor different alternative conceptions.

Research Paradigm

The discussion of the research paradigm will consist of two sections which provide a view of the theory of knowledge and the principles of research which guided the design and implementation of this research.

Epistemological Foundations

The following will consist of four subsections detailing the principles of knowledge which guided the conduct of this research. Each section delves into an important aspect concerning the growth of knowledge in terms of cognitive processes, conceptual change, or inferential reasoning.

The Nature of Knowledge. Science is the result of human action in the process of creative imagination in an effort to impose order on nature; to find patterns in nature. Scientific knowledge which results from the application of scientific processes by the various specialized sciences contributes to an overall conceptual scheme which is internally consistent. The formation of a theory within this conceptual scheme does not, as Kaplan (1964) argues, involve just the discovery of a hidden fact; the theory provides a framework within which to organize and represent them. The realization that facts are theory laden is related to our comprehension that without some form of structure observations and description would be unintelligible. The knowledge itself is formulated by and from the fundamental concepts which are pervasive throughout the various specialized sciences and are, in effect, a product of the culture.

This has been elaborated by Pratt (1978) with his indication that individuals grasp the world through their conceptual apparatus, a theoretical framework which represents the categories through which their experience is gained. Without this a prior conceptual framework experience would not be intelligible nor distinctions possible. An individuals system of concepts imposes categories, divides experience into discrete items between which relationships become possible.

Theory guides the search for data and the systematic patterns encompassing the data. Theories are not, as Kaplan (1964) indicates, accessories after the fact, on the contrary, they function throughout inquiry. Since human evolution involves thoughtful action whereby all human conceptualization depends on our recognizing or putting some kind of order into the world through scientific exploration, science can be viewed as an activity of human life.

Scientific theories provide an organized and systematized framework of data based upon experimentation by which the seeking of knowledge of natural phenomena can become meaningful. Nuniluoto and Tuomela (1973) contend that science looks for general patterns and regularities concerning a reality which exists independently of observers. This reality is knowable by means of scientific theorizing and experimentation aimed at the systematization of data rather than the mere collection of singular data.

This construction of reality whereby natural phenomena become meaningful does not involve an accumulation of knowledge, but an evolution or growth of knowledge. Popper (1965) argues that continued growth is essential to the rational and empirical character of scientific knowledge. This 'growth' of scientific knowledge involves the repeated replacement of scientific theories by better or more satisfactory theories. Moreover, this process involves the apprehension of problems of ever increasing depth whereby scientific progress proceeds from problems to problems. The awareness of a problem challenges us to learn, to observe, to experiment, and to advance our knowledge.

Thus scientific knowledge is in a continuous state of change. It is tentative and therefore does not purport to be 'truth' in an absolute and final sense. Science as a body of knowledge concerned with the explanation of natural phenomena is dynamic and when confronted with unexpected observations must, as Kuhn (1977) pointed out, "always do more research in order to further articulate its theory in the area that has just become problematic." In most cases, scientific exploration provides information for the refinement or readustment of various aspects of a conceptual structure. Occasionally, major scientific revolutions, during which time the normal-scientific tradition changes and there is a re-education of the scientific community's perception of its environment, result in the alteration of entire fields of science. Kuhn explicates this process when he states:

> Discovery commences with the awareness of anomaly, i.e., with the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science. It then continues with a more or less extended exploration of the area of anomaly. And it closes only when the paradigm theory has been adjusted so that the anomalous has become the expected. (Kuhn, 1979, p. 52)

An understanding of the nature of science involves an awareness of science as an evolving experimental discipline whose basic principles are subject to reconsideration and revision when new observations or new interpretations reveal that the present framework is inadequate. Thus, to better understand science and therefore to more realistically be involved in the process of science, one must comprehend the process of conceptual change.

Conceptual Change. While theory construction involves selecting from the materials of experience, Kaplan (1964) argues that it also involves a conceptual aspect whereby the selected materials form the foundation for the formulation of a conceptual matrix with no counterpart in experience at all. The background conceptual matrix is not merely reorganized, for knowledge does not grow by accretion nor merely by the replacement of dubious with more sound ones, but by the giving of new meaning through the remaking of the old cognitive matrix into the substance of a new theory.

The growth of scientific knowledge through theory construction involves a change in the conceptual matrix. It can be characterized as involving a conceptual change from the conceptual matrix Q1 to the less limited Q2. This adoption of Q2 in place of Q1 means that the world can be described in a more profound and specific fashion such that information not expressible without the theoretical concepts of Q2 can now be processed. Werner (1957) clarifies this process of change from Q1 to Q2 when he states that:

> Whenever development occurs it proceeds from a state of relative globality and lack of differentiation to a state of increasing differentiation, articulation, and hierarchic order.

This new conceptual matrix is less limited in its ability to describe and explain phenomena in that it provides the educational community with greater ability to make distinctions and seek out patterns. This process goes beyond mere linguistic enrichment, it involves new meaning.

With such a characterization of theory construction as conceptual change we can visualize a process whereby Q1 (i.e., the input) is channeled through the system and results in modification of its existing parameters, eventually resulting in Q2 as output. This description interrelates an internal state description with a functional analysis of the input-output. Laszlo (1973) points out that describing conceptual change as a process interrelating a system and its structural-dynamic structure with inputs and outputs involves system-cybernetics. Instances of the system-cybernetic process can be found in societal processes such as is evident in the conduct of scientific inquiry, as well as in the area of cognitive processes.

The utilization of cognitive processes during the course of scientific inquiry involving a change from one conceptual matrix to another entails not only scientifically observable objective events, but also events which can only be examined by introspection and which make up the direct and internally demonstrative experience of each of us. Laszlo (1972) indicates that these internal sets of events may be denoted mental events and that the system of mind events can be characterized as a cognitive system explorable through the concept of system cybernetics. It can thus be concluded that since introspection is required for the change from Q1 to Q2, mental events are necessary for the process of conceptual change to proceed.

Adaptation to environmental disturbances, which results in a conceptual change, involves the reorganization of the existing conceptual matrix to fit the actual flow of sensory experience. It is a process which involves learning. Confronted by a problematic situation the cognitive system must change if it is to learn and thus attain a higher level of cognitive functioning. Laszlo (1972) argues that the "adaptation of the cognitive system to its environment can only come about through the elaboration of new constructs which match the anomalous experiences and hence endow them with meaning" (p. 129). Any process which results in learning necessitates the attainment of an adequate symbolization of the significant relations in the perceived and inferred states of the systems environment through a reorganization and elaboration of the cognitive system.

The process of adaptive self-organization is an aspect of a cognitive system which conduces it toward states of higher negative entropy. It is when the system is in a state of progressive organization that the entropy of the system actually decreases (cf., Laszlo, 1972). Moreover, when there is a decrease of entropy the cognitive system gathers information. A cognitive system is thus a dynamic ordered whole, which evolves toward increasingly informed states. An important aspect about conceptual change and growth in relation to scientific inferences is that as suggested by Nuniluoto and Tuomela (1973), they provide expanded potentialities for the expression and processing of information which was not expressible within the original conceptual framework. Thus, it is necessary for conceptual change and the resultant growth of scientific knowledge that the information content increase.

Cognitive Systems and Information. It can thus be argued that cognitive systems are information-processing systems, and therefore we can apply the concept of information to mental systems. The conceptualization of an information-processing system involves the formulation of an abstract model having applicability for the description of how an individual, or in our case the scientific community, processes what Newell and Simon (1972) have referred to as "task-oriented symbolic information" (p. 5). In this case the task is that of the educational community to explain complex psychological phenomena. The information-processing approach to the investigation of a cognitive system utilizes postulated processes or operations and interdependent capabilities of the system to assist in the explanation of the processes by which judgements are made and problems resolved within a task environment. The concept of a 'task environment' has been elaborated by Newel and Simon (1972), and refers to an environment which is goal-oriented in the sense that there exists a task or problem to be encountered.

Observations provide information, and Hilpinen (1970) suggests that scientists make observations because it is an assumption that they provide information concerning hypotheses in question, and because an aim of inquiry is to obtain information. Yet the singular action of observation is limited in its potential. Kaplan (1964) argues that the content of our experience is not merely a succession of discrete observations, but consists of a sequence of events which are meaningful both in themselves and in the patterns of their occurrence.

Conceptual change and the associated growth in scientific knowledge can be viewed as involving a change in belief. It can then be argued that semantic information is involved in conceptual change since, as suggested by Jamison (1970), change in belief is the most philosophically relevant notion of semantic information, since the definition of semantic information is based upon the concept of information as a change in belief. Therefore, the process governing scientific inferences may be viewed as involving the acquisition of semantic information.

Laszlo (1972) elaborates upon the association between semantic information and the growth of knowledge when he submits that the question is whether the reorganization of a conceptual matrix in a cogntive system involves an overall statistical gain in information content. The supposition is that as a social psychological system the scientific process has a gain in information content when Q2 is greater than Q1. This gain in information content is associated with a gain in the level of organizaton as a result of the reorganization of the basic structural parameters of the system.

Within the interpretive framework which involves a semantic representation of natural phenomena, our fundamental interest is directed toward delineating the different alternative representation of the natural phenomena in question. The more of these alternatives a semantic representation admits of, the more probable it is; while the more alternatives a semantic representation excludes, the more informative it is.

Since a cognitive system must gain information content to remain viable when interacting with the environment our interest is thus drawn toward representations which restrict the potential alternatives. It is in this context that we must explore the process of scientific inference and the resultant growth in knowledge. We have determined that the growth of scientific knowledge involves conceptual change through the use of mental events which occur within a cognitive system involving the process of information transfer. Thus, the important factor in the growth of knowledge through inferential reasoning is the information content of our representation of the world.

Inferential Reasoning. The exploration of the dynamics of the growth of knowledge effectuated an awareness of the significance of conceptual change for the continued evolution of knowledge and the importance of information content for the change from Q1 to Q2. Conceptual change, as the principle means of the evolution of knowledge, necessitates a less limited notion of theory appraisal than reduction of uncertainty (cf., Salmon (1966)), or hypothesis testing (cf., Hacking (1965)). The reduction of uncertainty does not adequately model our search for reality since, as Jamison (1970) suggests, reality is far too rich and varied to be adequately reflected in a logical theory of probability involving the degree of confirmation. These deficient approaches are each founded upon an aspect of what Hanna (1980) refers to as the false dilemma. These views involve on the one hand the belief that inferential reasoning must be based upon deductive arguments resulting in certain truth or upon inductive arguments resulting in probable truth. Pratt (1978) argues that:

> ... it is impossible to get outside all conceptual schemes, impossible to describe reality as she "really is", and thus impossible to achieve a position from which the truth of any claim made within a conceptual framework may be "externally" assessed. (p. 58)

Thus, there will be difficulties with any attempt to show a theory to be true. Hanna (1980) argues that while informative theories are not necessarily true, neither are true theories necessarily informative. Thus, there will be difficulties with any attempt to show a theory to be true.

We will therefore reject the support paradigm and will attempt to show that since information is an important aspect of all cognitive system's it is the parameter of interest for appraising scientific theories. Moreover, it will be recognized that showing a theory to be false is immensely more effective in the appraisal of theories. Pratt (1978) submits that the aim of social science should be to use its observations to dispose of theories as opposed to the traditional methodology of trying to arrive at theories on the basis of an inductive inference from observations.

This emphasis upon falsification is a consequence of the quest for evidence with high information content. Popper (1968) argues that while we can not verify or confirm hypotheses, the most informative new observations will be those which falsify the previously preferred generalization. With this view of the scientific enterprise, Hanna (1980) submits that the intent of inferential inquiry is to discover evidence and formulate theories which increase our information about natural or sociological phenomena. Popper (1968) suggests that the greater the amount of empirical information or content a theory contains the greater the predictive or explanatory power will be; and as a more highly informative theory, it can thus be more severly tested as a result of the comparison of predicted facts with observations. Thus, in this view, an important aim of the inquiry process is to formulate theories with a high degree of falsifiability, or testability. Hanna (1980) emphasizes that with increases in the degree of falsifiability there are increases in the quantity of empirical information transmitted by a theory. Thus, the information paradigm which is being proposed for the appraisal of theories has as its foundation the determination of the amount of actual or potential information a theory provides regarding the relevant empirical observations of natural phenomena relative to background knowledge or competing hypotheses.

Within this information-theoretical framework, we can assess the explanatory power of theories (i.e., conceptions put forth by the scientific enterprise, student conceptions of scientific phenomena) stated in the language Q2 with respect to the theoretical concepts and observational generalizations in Q1 (cf., Hanna, 1980). If, however, the information content of a composite hypothesis is obtained from the data which is to be explained then that information does not have any explanatory value.

In this regard, it is the scope and precision of a theory's predictions that provide a measure of its testability. Whereas, Hanna (1969) suggests that:

> ... the essential characteristic of description, as opposed to explanation or prediction, is that a substantial portion of the information required for the account is transmitted by the data, rather than by independent environmental factors. (p. 321)

In the educational setting it may be more appropriate, especially in case studies, to begin with the formulation of descriptive theories before one attempts to develop theories with predictive, or explanatory power. It would thus be more appropriate to look at particular research data as having a measure of descriptive power (cf., Hanna, 1980). Thus, with experimental arrangements which cannot lead to explanatory or predictive theories the most which can be expected is a descriptive representation of phenomena.

Methodological Foundation

This section will provide insights into the various aspects of the methodological foundation within which this study was conducted. These include the assumptions and guiding principles concerning research on teaching, and the potential for generalizaton from the observed patterns of conceptual change.

It has been argued (Hanson, 1958; Toulmin, 1961; Kuhn, 1962) that scientific theories are radically underdetermined by experience and that although scientific theories must be testable by experience, they need not arise merely out of experience. They contend that what even counts as experience is necessarily theory dependent. Petrie (1972) suggests that experience can not be described independently of theory since a neutral observation language does not exist. The direction whereby the influence of theory upon observation is ignored has resulted from the inability of the functionalists to see that some empirical results have the significance they do because of the observational categories and theory in which they are embedded.

It is thus evident that some form of holistic philosophically confirmable foundation must provide a guide to observational methodology and inferences. Dunkel (1972) asserts that "some kind of normative base must be found if education is to be more than a mindless technology, ..." (p. 93). The distinction formulated by Kant (1787/1965) between judgements that are arrived at synthetically rather than analytically is instructive. He argued that the synthetic judgement process is expansive whereas the analytic is simply explicative. Utilizing this argument as an aspect of his contention for an increased emphasis upon the constructivist approach in educational research, Magoon (1977) points out that "man mostly comes to know his world by actively constucting it, and not so much by the passive reception of inputs" (p. 657). It seems clear then that some form of inferential reasoning is necessary in order to pursue a more complete understanding of concept formation.

Research on Teaching. It is possible to distinguish five facets of research on teaching which can be further characterized as quantitative, or qualitative. The quantitative approaches (i.e., Process-Product, Carrol Model and Aptitude-Interaction) to research on teaching share a number of guiding assumptions. The major assumption is that any relationships between teacher behavior and student achievement is law-governed. Secondly, an emphasis is placed upon only the observable behavior of the teacher. However, the qualitative approaches (i.e., Ethnographic and Teacher Thinking) are guided by the assumption that the teaching-learning process is rule-governed as opposed to law-governed.

It has been argued (Lott, 1981) that the application of the quantitative approaches to research on teaching have lead to limitation in the practical application of their findings. It follows from these perceived limitations that the research being described has its foundation in the qualitative approach to research on teaching. However, while this research is based upon the guiding assumptions of the qualitative approaches, it acknowledges the importance of several propositions which are found in the quantitative approaches.

An important relational consideration is that between process and product variables. The process variables are seen as interactive variables, between teacher classroom behavior and pupil classroom behavior. These process variables influence changes in pupil behavior, which result in the product variables of pupil growth. The modification of the Carroll model by

Bloom (1974) introduced the concept of prerequisite learning and the need for a student to master the necessary skills before encountering the next task to be learned. The importance of cognitive entry characteristics has recently been reemphasized by Bloom (1980) with his contention that "much of the variation in school learning is directly determined by the variation in students' cognitive entry characteristics" (p. 383). This is also in agreement with the Aptitude-Treatment Interaction (ATI) approach whose key characteristic is the concern for the interaction between the individual and the treatment, or environmental factors. Aptitude X Treatment interactions are defined by Cronbach and Snow (1977) as being present "when a situation has one effect on one kind of person and a different effect on another" (p. 3). They then go on to suggest that aptitude measures and educational methods should form a mutually supporting system.

The limitations of quantitative-oriented research apprehended by some researchers has lead to the utilization of different approaches to research on teaching. These qualitative approaches make the assumption that teachers and students are purposive agents whose thoughts influence their behavior (cf., Magoon, 1977; Johnson, Rhodes & Rumery, 1975).

Ethnographic research is based upon several assumptions regarding the educational process. First among these is that an important source of explanation for classroom phenomena is the social context in which teaching and learning occur. The members of the observed situation are regarded as knowledgeable beings whose behavior is purposeful and meaningful in this context. Magoon (1977) contends that the teacher and students are "purposive agents whose thoughts, plans, perceptions, and intentions influence their behavior and moderate the effects of behavior" (p. 652).

The key characteristic of the Teacher Thinking model of teaching is that the teacher is a rational and intelligent individual faced with a very complex situation. Clark and Yinger (1979) point out that the research focus should be the mental processes underlying behavior whereby an emphasis is placed upon attempting to understand teachers' judgement and decision making. An important aspect of this approach is its acknowledgment that the teaching environment involves complex interdependencies between behavior and environment (Yinger, 1978).

As a qualitative-oriented study the research being conducted is attempting to look at the interaction of process and product variables and aptitude-treatment interactions in a new light. The methodological techniques will, it is hoped, provide a more unified approach to research on teaching. The questions of interest are "What is the relationship between a teachers' interactive decision making and the patterns of conceptual change?" "What are the relationships between environmental factors and the patterns of conceptual change?" "What is the relationship between students' prior knowledge and the patterns of conceptual change?"

It is important to note that the types of thought processes exhibited in classrooms appear to be very dependent upon the nature of the cognitive task focused upon. Research must take into consideration the importance of the environmental factors influencing instruction (cf., Weinstein, 1979), and the process of social interaction (cf., Piaget, 1971).

Interaction, the key concept in the ATI approach, has been described as behavior being a function of the individual and the environment (i.e., of the aptitude and the treatment). However, this ignores the reciprocal nature of interaction in which the three entities of behavior, the individual, and the environment, are each affected by the other two in a continuous, simultaneous and sequential manner. The treatment may itself be altered by the individual, and includes the social context of instruction.

The two scientific disciplines referred to by Cronbach (1957) answer formal quantitative questions. What is needed to extend the paradigm and provide descriptive data for further research is systematic inquiry relying upon naturalistic and qualitative approaches to research.

Generalizability. The question of generalizability need not, however, be a point of contention. Eisner (1981) suggests that the belief that the general resides in the particular provides a framework within which generalization is possible. Qualitative research and the inferential process aimed at formulating conjectures attempts to provide insights that exceed the limits of the unique parameters of time and space within the situation in which they emerge. The researcher believes that the particular has a contribution to make to the comprehension of what is general and thus he is interested in making the particular vivid so that its qualities can be experienced.

Theoretical Foundation

The utilization of a model as an organizing framework implies an inherent way of thinking about the phenomena under study and as such places limits upon the kinds of research questions asked, the methods of inquiry employed, and the rules of evidence used to analyze and interpret data. The research program being described has a theoretical framework concerning learning, teaching, and the milieu of the educational setting.

Information-processing

It is argued that cognitive systems are information-processing systems, and therefore we can apply the concept of information to mental systems. This study of the teaching and learning process is thus founded upon the information-processing theoretical framework within which the teacher is viewed as an information processing decision maker (Shulman & Elstein, 1975) who provides a task environment intended to promote intellectual development, and the participants are viewed as goal-oriented information-processors and decision makers (Smith & Berkheimer, 1977) who utilize the internal capabilities of problem solving and thinking (Gagne, 1977).

The conceptualization of an information-processing system involves the formulation of an abstract model having applicability for the description of how an individual processes what Newell and Simon (1972) have referred to as "task-oriented symbolic information" (p. 5). The information-processing approach to the investigation of a cognitive system utilizes postulated processes or operations and interdependent capabilities of the system to assist in the explanation of the processes by which judgements are made and problems resolved within a task environment.

Researchers using the information processing approach to study learning view learning as conceptual change involving some analysis and transformation of what has occurred through the encounter with the task environment. The basis for this important theoretical development has evolved in conjunction with the assumption of structural complexity (Piaget, 1971; Laszlo, 1972) whereby the human organism can be viewed as a complex adaptive open system. The information processing approach utilizes postulated organismic processes or operations (i.e., the processes and operations used by the human organism to interpret and manipulate information) and interdependent capabilities to assist in the explanation of human thought. An important aspect of this approach is the identification of the processes and strategies the human organism uses in a particular task environment.

Gagne's intent has been to seek a broader degree of generality than the "'simple' prototypes of learning" (1977, p. 74) utilized by experimental psychology and to account for the processes and phases of learning in addition to the capabilities produced by learning. His theoretical formulation, which is founded upon the research concerned with internal processes, has assisted in providing a viable hypothesis for the analysis of the conceptual requirements for learning and the design of instruction.

An integral aspect of this conceptualization of learning is the occasioning of a problematic situation. That is, the provision of an educational situation whereby elements of the subject matter selected by the teacher, when juxtaposed with the student's present conceptual framework, will result in a conceptual incongruity. The importance of conceptual incongruity occasioned through a problematic situation has been explicated by Piaget (1960) and Berlyne (1965). It is through the resolution of these problematic situations by means of problem solving processes that the conceptual framework becomes more differentiated and a new level of cognitive functioning is achieved.

Case (1975) recommends that the design of instruction take into consideration the child's information-processing limitations such that the individual can cope with the informational demands of the learning situation. Thus, the generation of learning experiences would involve not only an analysis of component skills but also their functional organization. He contends that the "assembly of lower-order skills into higher-order skills is presumed to be possible only if the child's capacity for coordinating information is not overtaxed" (1978, p. 457). The framework for the "developmental approach" and its effectiveness were evaluated through the analysis of the extent to which material which was taught was retained over an extended period of time. The results of the investigation were supportive in that for one example eighty percent of those who were involved in the developmentally based curriculum formulated by Case showed a degree of mastery attained by only twenty percent of those who did not have the developmental approach. Other studies which were sighted also supported the value of this approach to some extent.

Conceptual Change

Conceptual change involves a change in the conceptual framework of the student through the action of internal mental capabilities during involvement in learning tasks. It is a process by which an individual comprehends a problematic situation within the task environment. The intellectual participation required on the part of the student involves requisite operations and conditions in terms of abstract structures (i.e., conceptual framework) and identifiable actions (i.e., cognitive strategies) within situational constraints (i.e., task environment).

A characteristic of conceptual change is that the subject must elaborate or transform the current conceptual framework to reconcile internal discrepancies. An emphasis is placed upon the interaction between the subject's internal processing of information and the encounter with the environment. It considers the environmental context as well as the intentions of the teacher and student to be important factors in the reconciliation of internal conceptual conflicts. It is within this context that Posner, Strike, Hewson, and Gertzog (1982) argue that "a new conception is unlikely to displace an old one, unless the old one encounters difficulties, and a new intelligible and initially plausible conception is available that resolves these difficulties" (p. 220).

The model of 'teaching' which results from the adoption of this model of conceptual change requires more of the teacher than simply the occasioning and structuring of content. Moreover, the student is required to go beyond the apprehension of the information content and its integration into the conceptual framework and must produce a way to deal with the incongruous situation. The model accepts the constructivist philosphy as suggested by Magoon (1977) where the teacher and students are seen as "purposive agents whose thoughts, plans, perceptions, and intentions influence their behavior and moderate the effects of behavior" (p. 652). Student and teacher interaction is further influenced by communication difficulties brought about by the use of different interpretive frames by the teacher and student (Driver and Easley, 1978). Unlike the first model (i.e., Process-Product) which places much responsibility upon the teacher and the Carrol Model which places emphasis upon the subjects participation (i.e., time on task), this model recognizes the mutual accountability of each.

Based upon the model, changes in conceptual framework will be influenced by the interaction of environmental factors such as teacher and student acts within the framework provided by the learning experiences and the internal reconciliation processes of the student. This will have begun with the teacher occasioning a discussion directed at having the students' interpret the evidence gained from their classroom experiences. The patterns thus exposed are used to influence the subjects to justify their current conceptions in the light of the encountered evidence and where necessary reconcile concflicting conceptions. It is this episode in the instructional sequence which will make public the alternative frameworks used by the students in response to what Nussbaum and Novick (1982) refer to as an "exposing event" (p. 4). The teacher's skillful probes using student alternative frameworks along with empirical and theoretical evidence leads to the subject restructuring his/her interpretive framework.

Analyzing the patterns of conceptual change can lead to an understanding of the relationships between the task environment, concept formation, and the process of conceptual change. Individuals have different conceptions of subject matter and apprehend curricular tasks in various ways. It is through an understanding of the patterns of conceptual change that appropriate learning experiences can be selected and occasioned in an effort to support or enhance the development of conceptual frameworks.

Teaching-Learning Process

Teaching will be viewed as an intentional and systematic activity. It is intentional in that some change toward a specified end on the part of the student is contemplated. It is systematic in that direct attention is given to a set of actions, within a specified structure and situational context, which intervenes between tasks of the teacher and tasks of the student. Teaching and learning may also be looked upon as a form of linguistic activity. Dunkin and Biddle (1974) point out that the analysis of teaching as a form of linguistic activity is not familiar to many educators, although the symbols with which the exchange of ideas in an educational setting are conveyed helps clarify meaning.

In this study the teaching and learning process will be viewed as involving systematic and linguistic events, and the research interest will thus be to examine patterns of linguistic events. Influenced by the view that "systematic structures and processes underlie language use" (Slobin, 1979,

p. 6), the approach will involve the examination of the discourse as a result of field observations. Dunkin and Biddle (1974) have pointed out that linguists have begun, through the study of semantics involving the relationship between language form, users, and meaning, to generate valuable concepts for the analysis of classroom discourse.

The belief, upon which this study is based, is that once the propositions that appear in the sentences of speakers are clearly represented the structure of their ideational exchange should become clear. However, the syntax, or system of linguistic structure, is only one aspect of a linguistic event. Thus, the current study will not only utilize syntactical structure, but also semantics in an attempt to determine the meaning of the discourse, since "the semantic system of language forms the interface between language and thought" (Foss and Hakes, 1978, p. 48). Therefore, the appropriate approach is viewed to be the development of observational techniques based upon linguistic analysis.

Parallels And Principles

In addition to reviewing the previous research which provided background for this study, this chapter has explored the theoretical and methodological assumptions which guided the design and interpretation of this research. The nature of scientific knowledge, conceptual change and cognitive systems was reviewed owing to the belief that there are parallels between the nature of the growth of scientific knowledge and student learning (i.e., growth of knowledge). The review of the theory of knowledge and principles of research which guided the design and implementation of this research was incorporated in an effort to provide the reader with insights concerning the view of the world which influenced the design of data collection procedures and the conduct of the analysis process.

The parallel between social (e.g., scientific community) and intellectual changes has been suggested by Toulmin (1972) who states that like the institution of science, individuals "change by selective innovation in response to changing situations, in the name of collective social goals, and in this, too, they display an unremarked parallel to concepts and conceptual evolution" (p. 353). In the educational setting it is asserted that knowledge (i.e., concepts) is a product of the culture of the classroom. Just as with the scientific community, individuals grasp the world through their conceptual apparatus, a theoretical framework which represents the categories through which their experiences are gained. The growth of knowledge (for an individual, for a community of scientists) leads to the 'giving of new meaning,' however, the background conceptual matrix is not merely reorganized, the existing conceptual matrix is changed to fit the actual flow of sensory experience.

The review in this chapter of such topics as the nature of inferential reasoning and conceptual change was meant to give the reader a perspective of the principles which guided the design and interpretation of this research. The reasoning reviewed in those sections suggests that the formation of a theory (e.g., a theory of conceptual change) does not involve just the discovery of hidden facts; it involves the search for general patterns and regularities concerning a reality (i.e., the utilization of cognitive processes by an individual during the course of scientific inquiry in an educational setting) which exists independently of observers (e.g., the researcher). This reality is not knowable by means of the mere collection of singular data; it entails not only scientifically observable objective events, but also events which can only be examined by introspection and which make up the direct and internally demonstrative experience of each individual. Thus, to get at the patterns and regularities inherent in events only examined by introspection, observational techniques and clinical interviews must be used in a unified data collection system.

The material discussed regarding the epistemological, methodological and theoretical foundations provided an organizing framework which guided the development of the observational methodology and the making of inferences. The value in considering the arguments concerning research on teaching and cognitive systems as information-processing systems, has been that potentially useful questions that might not otherwise have been asked were perceived and played a guiding role when observing events, or analyzing data. The arguments revealed in this chapter were intended to make it clear that the design of the methodology and the conduct of the research was guided by the assumption that the teaching-learning process is rule-governed and that teachers and students are purposive agents whose thoughts influence their behavior.

It seemed clear that there must be an acknowledgement that the teaching environment involves complex interdependencies between behavior and environment and that an important source of explanation for classroom phenomena is the social context in which teaching and learning occur. Moreover, the arguments in these sections have suggested that the important factor in formulating a methodology which would lead to the growth of knowledge through inferential reasoning (i.e., give researchers the capability to gain new insights into the process of conceptual change) is the information content of our representation of the world. Thus, it was felt that there must be a more unified approach to the research and that it should take into consideration the importance of the environmental factors influencing istruction and the nature of the cognitive tasks.

CHAPTER 3

PROCEDURES

The intent of this chapter is to provide a view of the environment in which data collection occurred, and the procedures and techniques used. In addition, the techniques used to interpret and analyze the data once organized will be discussed.

DATA COLLECTION

The purpose of this section is to describe the context within which the study was conducted and the procedures for data collection and organization. The function of the data collection methodology was to provide sufficient information from which changes in a student's inferred conceptual framework could be identified. It is important that the data be complete and organized for efficient and effective analysis. The case study, group data and target student data must provide an adequate and accessible data source for conceptual change analysis.

Context

The context in which this study was conducted included an instructional unit, the subjects who experienced the instruction, the teacher who guided the instruction, and the school and community in which the instruction occurred.

Instructional Unit

The curricular unit which provided the instructional context for this study was the "Producers" unit of SCIIS Communites as revised by Smith, Anderson, and Berkheimer (1981). The revised teacher's guide was designed to make the conceptual change aspects of the instruction more explicit than they had been in the original SCIIS guide.

The literal program had many features which were designed to help bring about changes in students conceptions. This involved student participation in experimental set-ups and corresponding key questions which were intended to guide the observation and interpretation of phenomena. The strategy referred to is represented in Table 1.

The unit begins with the student's dissecting bean seeds and examining the contents. They learn that there are parts to a seed; the cotyledon and the embryo. The question is raised "What do these parts do as the plant grows?" This leads to the set-up of an experiment where the students germinate bean seed parts (embryo, cotyledon, embryo with one cotyledon, and whole seed). From their observations they would observe that the embryo is the part of the seed that grows into the new plant. They also observe that whole seeds and embryo's with one cotyledon attached usually grow while separate embryos and separate cotyledons do not.

The next chapter in the unit explores the question "Do plants need light to grow?" Students grow grass in the light and in the dark. It is during the experiments in this chapter that the students would observe a number of events which were intended to be difficult to explain if they held the common misconception that soil is a source of food for plants. They would see grass seed sprout and begin to grow in the dark, then generally wither and die. The intended explanation to result from this observation is that it occurs because the food stored in the cotyledon runs out. This leads to the "invention," by the teacher, of the concept of photosynthesis which is intended to explain the observations better than the idea that plants get their food from the soil.

The final chapter in this unit provides an opportunity for the students to observe the growth of bean seeds under four different conditions: in the

TABLE 1

SUMMARY OF THE STRATEGY FOR CHAPTER 3 - 6 OF SCIIS COMMUNITIES

Strategy Elements			
Framing Question	Empirical Results	Presented Information	Intended New Conceptions
• Exploration Phase of the Learning Cycle			
Chapter 3: Looking at Seed			
1. What is inside seeds?	Bean seeds have a small plant-like part that is inside two larger halves	The small plant-like part is the "embryo", the two halves are "cotyledons".	Seeds have a small, plant-like part called the embryo and two larger part(s) called the cotyledons.
2. What do the embryo and cotyledon do for the growing plants?			
Chapter 4: What Seed Parts Develop and Grow			
3. What seed parts develop and grow? What do you think each part of the seed does?	Bean embryos develop into plants only when attached to a cotyledon.		

TABLE 1 (continued)

SUMMARY OF THE STRATEGY FOR CHAPTER 3 - 6 OF SCIIS COMMUNITIES

Strategy Elements: Framing Question	Strategy Elements: Empirical Results	Presented Information	Intended New Conceptions
Chapter 4: What Seed Parts Develop and Grow (continued)			
4. Why did the cotyledon and embryo live when joined?			The embryo develops into a new plant. The embryo develops into a plant only if it is attached to a cotyledon. The cotyledon provides food for the embryo.
5. Why didn't the cotyledon or embryo grow alone?			
6. What do the embryo and cotyledon do for the plant?			
Chapter 5: Do Plants Need Light to Grow?			
7. Do plants need light to grow? When?	Grass begins to grow in the dark and in light.		
8. Why are the plants in the dark growing so well?			Plants do not need light to begin to grow.
9. Which plants will survive better? Why?			

TABLE 1 (continued)

SUMMARY OF THE STRATEGY FOR CHAPTER 3 - 6 OF SCIIS COMMUNITIES

Strategy Elements			
Framing Question	Empirical Results	Presented Information	Intended New Conceptions
	Chapter 5: Do Plants Need Light to Grow? (continued)		
10. How could you make the yellow grass turn green and the green grass turn yellow?			Plants get food from their seeds (i.e., cotyledons).
11. What has happened to the grass set ups?	Grass continues to grow in the light but not in the dark.		
12. What does light do for plants?			
13. Why did the plants grow in the dark for awhile?			Plants do need light to continue to grow.
14. Where do plants get the food they need?			
15. Why did the plants in the dark die and those in the light live when both had the same soil?			

TABLE 1 (continued)

SUMMARY OF THE STRATEGY FOR CHAPTER 3 - 6 OF SCIIS COMMUNITIES

Strategy Elements: Framing Question	Strategy Elements: Empirical Results	Presented Information	Intended New Conceptions
Chapter 5: Do Plants Need Light to Grow? (continued)			
• Invention Phase of the Learning Cycle			
16. Can you explain the results using the idea of photosynthesis?		Plants use energy from light to make food from water and air.	Plants use light to make food out of water and air.
• Discovery Phase of the Learning Cycle			
17. What do you think will happen to young bean plants with and without cotyledons placed in the light and dark, respectively? Explain your reasons.	Bean plants without cotyledons grow in light, but die in the dark. Bean plants with cotyledons continue to grow in light, but stop growing in dark after the cotyledons shrivel and fall off.		

TABLE 1 (continued)

SUMMARY OF THE STRATEGY FOR CHAPTER 3 - 6 OF SCIIS COMMUNITIES

Strategy Elements			
Framing Question	Empirical Results	Presented Information	Intended New Conceptions
		Chapter 6: Cotyledons	
18. Which grew better: plants with or without cotyledons?			
19. How well did plants without cotyledons grow in the dark? In the light?			
20. What do you think the cotyledons do for a young plant?			The cotyledon provides food for young plants. After the food from the cotyledon is gone, plants need light to make their food.
21. When do plants need light?			

light with and without cotyledons and in the dark with and without cotyledons. The patterns of growth are consistent with the idea that plants get food from the cotyledons or make it themselves in the light, but that they do not get food from the soil.

Classroom

The classroom in which the observations for this study were made (twenty three lessons were observed over a ten week period) consisted of a three room semi-open classroom format. It was thirty feet by thirty feet with half of the rear of the classroom open to the adjacent classroom. This open area was occupied by several objects which formed a divider between the two classrooms. These objects consisted of a two-drawer file cabinet, the teacher's desk and a short three shelf movable bookcase. The students sat at hexagonal tables (each formed by putting two trapezoidal tables together) scattered about the room with four to five students at each table.

The entrance to the classroom was in the front of the classroom at the extreme left. Next to this entrance door was a door to the back room with the remainder of the front wall taken up by a blackboard. One-third of the left wall had a blackboard with the remainder taken up by a bulletin board. A table was kept below the blackboard for the storage of the tubs containing the science materials used by the students.

The outside wall of the classroom which adjoined the front wall was mainly windows with the exception of a door towards the rear of the classroom which opened to an expansive open area. All along this wall were several large plants (e.g., a six foot Norfolk Pine) while near the rear door and along the short (in length) wall in the rear of the classroom was a sink and wall cabinets.

Subjects

This study utilized a population of 22 fifth grade children. The children were of working class as well as professional parents with some (17%) being from minority (e.g., Black, Oriental, Hispanic) families. Four students from this group were selected, based upon their unique and interesting pre-instruction conceptual frameworks, from this group for more intensive study (e.g., focused observation and clinical interviews). This target group worked together as one of the groups into which the class was organized for science instruction.

Teacher

The teacher had nine years of experience in preschool through intermediate grades. She was responsible for the teaching of science to three groups of fifth graders in a team-teaching situation. Her educational background included a Masters degree as well as one science course, one science education course, and a half-day SCIS workshop. She had three years of teaching experience with the SCIS/SCIIS program.

School and Community

The classroom which was the focus of this study was in an elementary school with an enrollment of 320 students in grades K through 5. The school was part of a school district which had a student population of 4,450 at the time the field work for this study was conducted. The school district served a midwest suburban community having a population of 45,000 with an above average socio-economic status. The major financial influence for this multi-cultural metropolitan area was a major midwestern university.

Design

The design of this study took the form of case studies of a set of changes in an individual student's conceptions as he experienced instruction in the target unit. The inferential description of changes in student's conceptual framework was accomplished through the use of psychomodeling, observational, and clinical interview techniques to examine the patterns of conceptual change. These approaches to data collection provided the necessary information to formulate sequential representations of a conceptual framework, which were then in turn used to examine the patterns of conceptual change. The curricular unit provided the task environment for observation, the focal point for clinical interviews, and the propositional knowledge for psychomodeling instrumentation.

Data Collection Techniques

This section is concerned with the development and implementation of all data collection instruments and techniques.

Psychomodeling Instrument

As part of the Planning and Teaching Intermediate Science Study (Smith & Anderson, 1984), a psychomodeling instrument was developed for the "Producers" unit of Communities. The psychomodeling approach provided a general classroom view of student understanding of propositional knowledge addressed as well as subsuming and correlative concepts, and thus aided in the search for patterns based upon analysis of the target students. The instrument was used to collect data (1) for determining an individuals conceptual framework; and (2) for determining various conceptual frameworks within the classroom.

An important aspect of the development of this instrument was the segmentation of the instructional unit in such detail that the propositional knowledge addressed could be used to develop items. A literal program analysis of the "Producers" unit resulted in the representation of the organization of instruction and the listing of the propositions provided in

Appendix A. A literal program analysis provides a characterization of the propositional knowledge which would be addressed and student tasks occasioned if the suggestions in the instructional materials are followed literally.

This in turn was used to formulate items for the psychomodeling instrument which is provided in Appendix B. The observed task performance on the open ended, multiple choice, and true-false items are viewed as resulting from an application of an individual's knowledge and thus as providing a basis for inferences about an individual's underlying conceptual framework.

This paper and pencil test was based on elements identified in the literal program analysis to provide data for inferring an individual's conceptual framework or the conceptions of a group. The cross referencing of items on the test with specific propositional knowledge addressed provided a framework for the analysis of individual student's knowledge.

This aspect of the data collection included the administration of the psychomodeling instrument prior to instruction as well as after. As a pretest it was intended to provide information concerning the student's understanding of the concepts to be addressed prior to instruction. Use as a post-test involved a re-administration of the instrument used for the pretest. It was thus used to assess subject's level of understanding of the goal propositions. In addition, its analysis in conjunction with the pre-test provided a general view of patterns of conceptual change.

<u>Observation</u>

It is thought that conceptual change is influenced by the context within which it occurs, thus a representation of the context was attempted utilizing observational data. The application of observational methodology provided a detailed representation of the milieu in which instruction occurred. Classroom observation will provide an avenue for the description of teacher acts (i.e., pedagogical activities) and student activities. This will assist in the description of the sociological and psychological aspects of the classroom (i.e., the situational context).

Schatzman and Strauss (1973) have argued that the researcher must observe the context within which the process of interest occurs as the actions of the involved individuals:

> ... are best comprehended when observed on the spot -- in the natural, ongoing environment where they live and work. If man creates at least some of the conditions for his own actions, then it can be presumed that he acts in his own world, at the very place and time that he is. The researcher himself must be at the location, not only to watch but also to listen to the symbolic sounds that characterize the world. (p. 5-6)

The application of observational methodology can provide an approach from which the internal thought processes involved in teaching and learning can be explored. Nuthall and Lawrence (1965) assert that "the most significant contributions to the understanding of thinking in the classroom are likely to result from the meeting of psychological theory and the 'naturalistic' study of the teacher with his class" (p. 52). The observation and description involved in naturalistic studies of the classroom can expose the ways in which the teacher and pupils interact thereby providing observational data through which a variety of patterns of thinking based upon a normative conceptualization can be investigated.

Within this context, observational techniques for a study of conceptual change were formulated and utilized for data collection in a classroom setting as part of a preliminary developmental project (Lott, 1982a). The naturalistic observation and description exposed the ways in which the teacher and pupils interacted and thereby provided observational data through which patterns of conceptual change could be investigated. It was intended that the observational system provide a detailed representation of the situational context in which instruction occurred. This was accomplished through the use of the following instruments based upon the classroom observation.

The observation system consisted of three parts; observation notes focusing especially on the target group, audio tapes of group and class behavior, and the use of video tape at selected points in the instructional sequence. The observation notes were collected on the Classroom Observation Form which was completed during each lesson (see Appendix C). This form was completed as the observer watched the classroom events which made up the lesson. While providing some information concerning the class as a whole, this form is directed primarily at collecting information through observation relevant to the interactions of the target students. These completed forms provided the basis for all further analysis.

Audio tape recordings of each lesson were used as a supplement to classroom observation. Two tapes were made; the 'classroom' tapes contained the verbal statements within the classroom while the 'group' tapes provided a record of the statements made by the target students. The group tapes were recorded using a directional microphone suspended directly over their table.

Additional forms which were developed enabled the breakdown of instruction into student tasks and the preparation of a narrative description for each task drawing on observation notes and tape recordings. A literal program analysis (Sendelbach, 1980; Landes, Smith and Anderson, 1981), a process for the analysis of elementary school science curriculum materials, was the point of departure for these efforts. This analysis produces a detailed step-by-step account of what the classroom would be like if the teacher followed the recommendations in the Teacher's Guide 'literally.'

Most instructional materials are divided into individual lessons, each lesson containing a description of individual instructional tasks. These tasks specify what students are to accomplish at any given point in the sequence of instruction. Each student task identified for this study served as the smallest unit for the literal program analysis. They were characterized in terms of suggested classroom organization, teacher and student activities, as well as conceptual information content addressed. The purpose of the literal program analysis was to place the curriculum tasks in a form that would facilitate the comparison with the observed classroom instruction.

The Task Description Form (see Appendix C) was used to record a narrative description of the actions of the target students. This form was completed after each lesson and provided a detailed description of each task identified during instruction. The Lesson Summary Form (see Appendix C) was completed for each lesson observed to provide a unifying framework for the task description analysis and was intended to provide summary information about the lesson as a whole and its linkage to other lessons. This form summarized, at the lesson level, the function of the tasks as part of the instructional unit and identified the propositions asserted by the teacher and students.

In addition, selected lessons (i.e., those where an experiment was set-up and predictions made, and those where observations were interpreted) were video taped. Moreover, the audio tapes for these same selected lessons were transcribed. This was done in an effort to collect a more complete data base from which further analysis could be attempted.

Clinical Interviews

Clinical interviews (Pines, et al., 1978) were used to provide a controlled situational context in an effort to infer conceptual framework as well as follow it through the learning experiences. The interviews were used as an in-depth method for inferring conceptual framework; for ascertaining cognitive structure. This technique was used to elicit information from the subjects and to generate data for the purpose of answering questions about the patterns of conceptual change as well as the products (i.e., knowledge states).

The tasks utilized for clinical interviewing included those tasks designed to provide application experiences which were founded upon the concept of photosynthesis in the Producers unit or prerequisite to it. This procedure aided in the effort to obtain data which enhanced our understanding of conceptual change in the Producers unit.

The selection of tasks for inclusion was followed by the preparation of detailed protocols, patterned after those described by Pines, et al. (1978), which were used to provide a guide for the clinical interviewer. The propositional knowledge addressed by each clinical interview which was used in the formulation of the protocols was also used, along with the procedures developed by Smith and Sendelbach (1979), to complete expected conceptual frameworks for each of the tasks which made up an interview.

All clinical interviews consisted of two segments; each involving the use of problem questions. The first involved a brief non-task oriented session concerning the experiences and concepts addressed during classroom activities. The second was a task-centered activity in which phenomena were presented to the student to explore. During the exploration of these phenomena the student's thoughts were probed to determine relevant conceptions.

Each clinical interview consisted primarily of two patterns of questioning: 1) the presentation of a novel situation about which the student was asked to make, and then explain, a prediction, and 2) asking the student to recall the purpose and results of investigations conducted during instruction, to explain these results, and to predict and explain expected future results. Each clinical interview was recorded on audio-tape. These audio-tapes were then used to produce a typed transcript of all interviews and in turn a cumulative proposition list for each target student.

Clinical interviews enabled the researcher to determine the extent of conceptual development of subsuming and correlative concepts as well as student understanding of propositional knowledge addressed and the purpose and meaning of classroom tasks.

DATA ANALYSIS

The purpose of the data analysis process was the organization of the data base for the effective translation of relevant observational and quantitative information into interpretable patterns. The data analysis involved two phases. These phases were designed to provide greater refinement in data selection for further analysis.

The analysis of changes in conceptual frameworks as inferred from the data obtained from the psychomodeling instrument as well as discourse provided an avenue through which the patterns and parameters of conceptual change were described. A formal approach for representing conceptual frameworks and from which changes can be monitored is the "propositional network structure." An example of such a network is provided in Figure 4. This represents a modification of the "active structural network" which was developed by Norman and Rumelhart (1975). Moreover, this aspect of the study was built upon the research of Kintsch (1974) and Brachman (1977).

Phase I Analysis

The purpose of this phase was to identify the major changes that occurred in students' conceptions, the period of time during which they occurred, and the specific segment of instruction during which the students encountered information directly related to the change. A diagram of the process used for the Phase I analysis is provided in Figure 5.

Student Conceptions

The identification of the major changes that occurred in students' conceptions was done by representing the student conceptions at various points during the course of the study and the information content of the science lessons as lists or networks of propositions.

Psychomodeling. The psychomodeling instrument was used to collect data (1) for determining an individual's conceptual framework, and (2) for determining group conceptual frameworks. These inferred conceptual frameworks were then used to study the conceptual changes of individual's as well as groups of students. The use of the data collected for individual analysis involved describing subject's responses on a set of defined variables. The students' responses were first coded, using defined features of the responses, based upon the coding scheme developed by Smith (1982). From these codings, scores were computed for each student using a program written for an Apple II+. These scores reflected the amount of evidence supporting the inference of student belief in alternative propositions and interrelated sets of propositions.

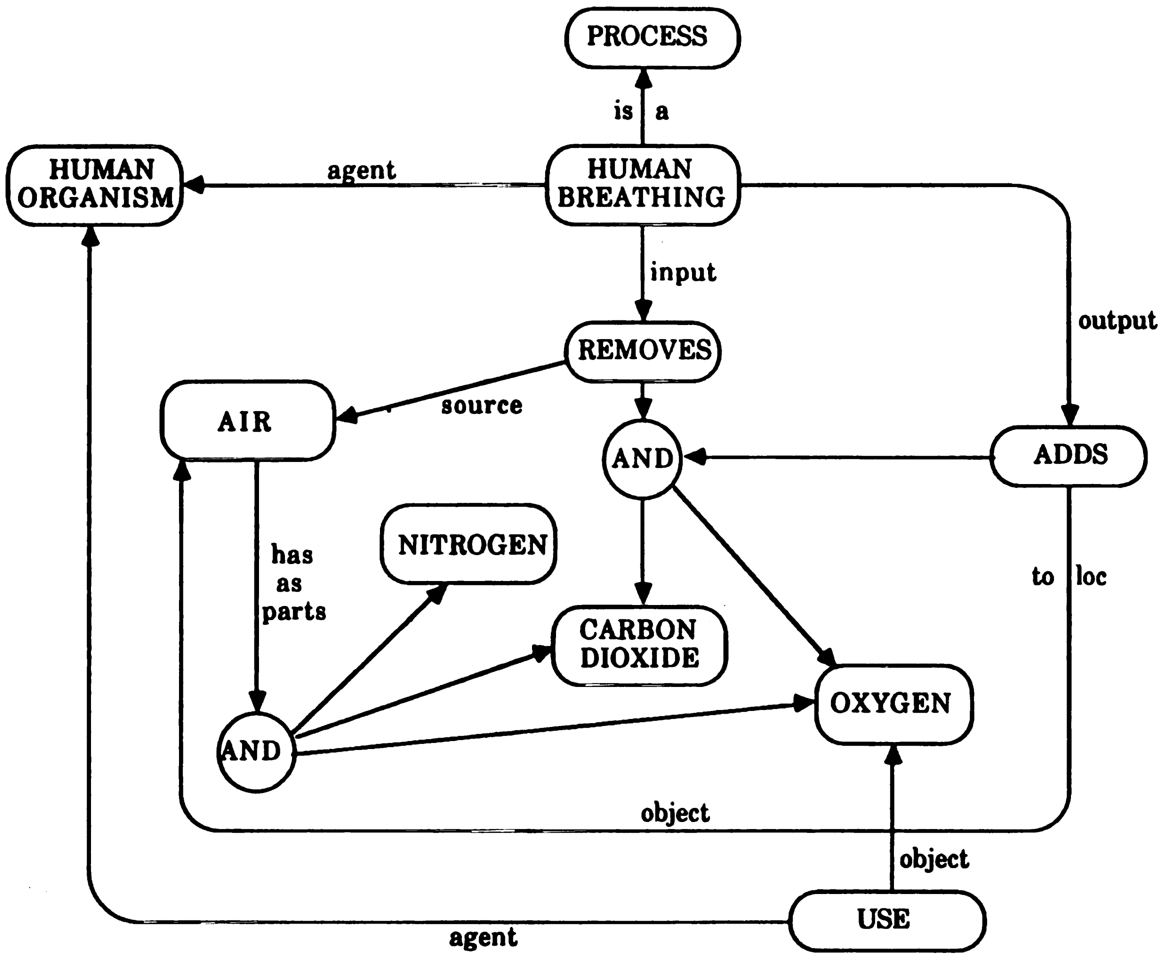


FIGURE 4. Example of Propositional Network Structure. (This provides a view of the data representation by which conceptual frameworks, and the changes over time, were inferred based upon data from the psychomodeling instrument as well as discourse.)

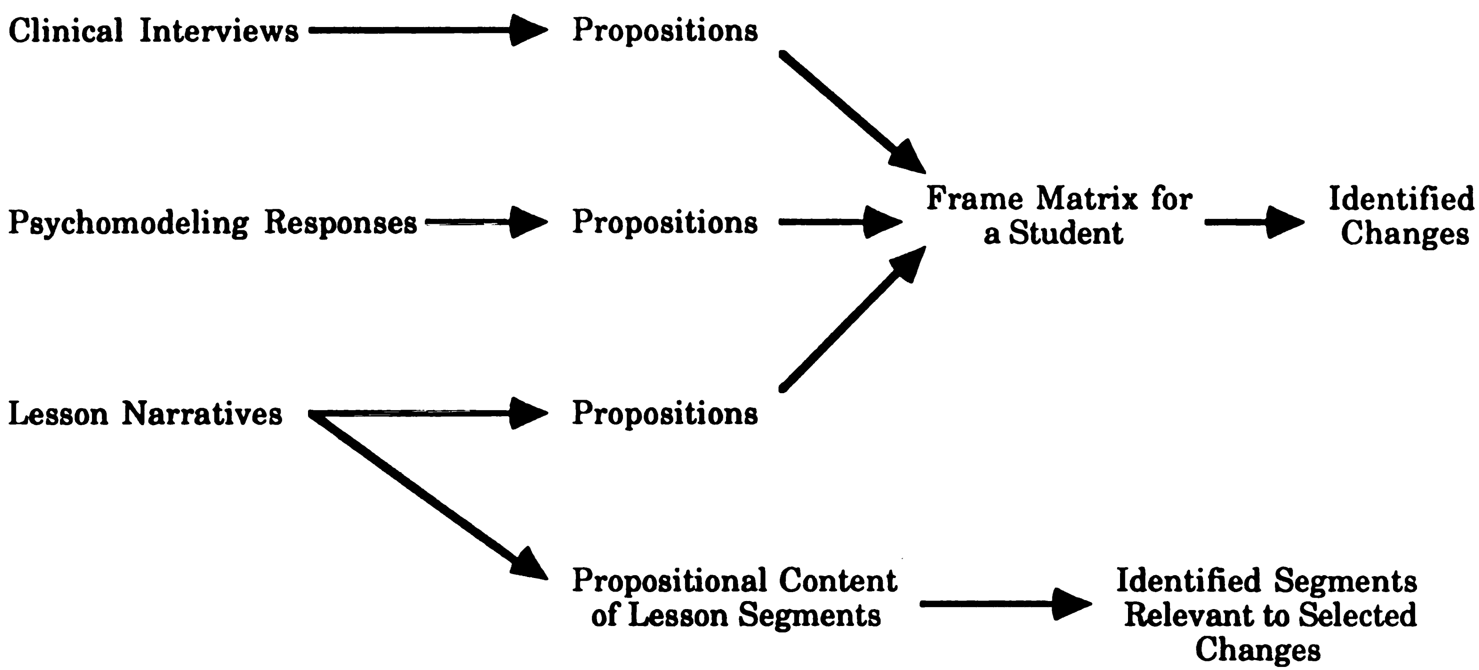


FIGURE 5. Diagram of Phase I Analysis Process (This provides a schematic representation of the data sources and products used to identify the major changes that occurred in students' conceptions.)

One must also have an approach for conceptions analysis. The procedures for analyzing student conceptions developed by Smith (1980) were revised and expanded prior to this study. The foundation upon which this methodology development was conducted evolved from research efforts at the Science and Mathematics Teaching Center in coordination with the Institute for Research on Teaching at Michigan State University (Smith, 1980a).

The patterns and parameters of conceptual change as determined for all the students were used to categorize the individuals selected for in-depth study through clinical interviews within particular patterns. The instructional activities identified in the program analysis, intended to bring about conceptual change, provided the framework for the analysis.

The results of such a process were used to explore the group patterns of conceptual change. Those students inferred to have a specific conception were selected out of the data file and their pre-test conceptions determined. In an effort to study the process of conceptual change it was determined which students possessed these conceptions and what conception resulted.

Clinical Interview. The procedure for the analysis of interview discourse involved the delineation of the propositions asserted during the interview process. A students' conceptual framework was inferred from data obtained as students explained the scientific phenomena encountered during the interview or as part of their classroom experiences. Propositions obtained from the clinical interviews on different occasions could be compared to identify changes in students' conceptions.

It should be noted that this was not an evaluation study; it was not intended to evaluate the student's achievement of content or their ability to hypothesize or explain. The inquiry skills of explanation and of hypothesis generation were only used as situational contexts for inferring an individual's conceptual framework.

Frame Matrix. An application of the suggestions of Minsky (1975, 1977) and Davis (1980) resulted in student conceptions and the information content of the science lessons being represented as lists of proposition 'frames.' These frames (see Appendix D) specified certain components of a proposition which were fixed and other parts which could vary.

In order to facilitate the analysis of conceptual change the formulation of frame matrices was undertaken. A 'frame matrix' was formed by denoting the data points (lessons, pre- and post-assessment, and clinical interviews) horizontally and the coded proposition frames vertically. The affirmation of a specific alternative frame was recorded at the intersection of the appropriate column and row.

These frame matrices, one representing propositional frames affirmed during instruction (see Appendix E) and one representing the propositional frames affirmed by the four target students who were the focal point of the classroom observations (see the frame matrix for Ben in Appendix F), provided an organizing framework whereby the sequential representations of propositions affirmed could be examined for changes. The completion of a frame matrix was based upon the analysis of the psychomodeling instrument, narratives and transcripts based upon classroom observations, as well as the clinical interviews. The frame matrix, as an analysis vehicle, provided insights concerning a student's interpretations of phenomena encountered as part of the instructional unit.

Identification of Changes. Propositions obtained from the psychomodeling instrument, clinical interviews or classroom observations and plotted on the frame matrix could then be compared to identify changes in students' conceptions. A strategy was developed with the purpose of providing for the organized search of the data base for relevant observations and quantitative data, and the effective translation of this information into a form useful for conceptual change analysis. The strategy included the following steps:

1) Review data from target classroom and select one of the target students:
    1.1) who has interesting and clear preconceptions, and
    1.2) for whom there is reasonably complete data.
2) Represent the student's preconceptions based upon results from psychomodeling instrument in terms of:
    2.1) Lists of propositions organized by topic and indicating source.
    2.2) Lists or diagrams of preconceptions organized by proposition frames and subtopic.
3) Select a particular preconception for selected student which:
    3.1) is fairly complete, and
    3.2) is interesting.
4) Identify lessons and tasks in the literal program in which the student would confront information related to the selected preconception.
    4.1) Examine the information content (set of propositions) of each task to determine if it would complete any propositional frame included in the preconceptions.
5) Analyze the relation between the preconceptions and the information content of the lesson.

5.1) for each relevant proposition (ones which would complete a proposition frame), characterize the relationship between the preconception proposition and the program proposition. Some relationships are:

5.1.1) Synonymous.

5.1.2) Directly contradictory.

5.1.3) Simple additive.

5.1.4) Inconsistent meaning of common concept? (NOTE: May be found if the frames were used to define 'related.' Inconsistent meaning may be due to different frame used by student.)

5.1.5) Other relationships (define type).

6) Predict changes that would be expected:

6.1) Specify the predicted change and represent it as a list or diagram.

6.2) Represent the changed state in a manner parallel to 2.

6.3) Explain the basis for each predicted change or lack of change which might have been predicted.

7) Describe/analyze the context in which the 'encounter' (between preconceptions and information content) takes place.

7.1) Question being asked, answered (in literal program)

7.2) Science task being performed/or information source.

7.3) Other interesting context (e.g., nature and significance of earlier tasks which may influence concept formation).

The above questions provided a focus whereby the data base input could be organized for effective analysis. The results were intended to provide an organizing framework which would assist in the description of patterns of conceptual change.

In each case the sequential representations of conceptual framework were examined for changes. It was then that determinations were made concerning the relationship of any changed conceptual framework with the desired framework.

Instruction

Once changes in students' conceptions had been identified interest was directed toward the representation of instruction, based upon information obtained from classroom observation. This process was made less difficult by using the literal program analysis which provided a characterization of the task organization and propositional knowledge of each chapter.

Segmentation. The segmentation of instruction (i.e., literal program analysis), which provided an identification of the student tasks which would be occasioned if the suggestions in the instructional materials were followed literally, was used to compare actual behavior with the program intentions.

Propositional Content. The literal program analysis identified the propositional knowledge to be addressed in the instructional unit. In order to facilitate the analysis, the proposition frames previously defined (cf., frame matrix representations) were used, in conjunction with the narrative and summary descriptions of each lesson at the task level, to document the propositional content addressed in the instruction as well as that observed in student responses.

Identification of Relevant Instructional Segments. The lessons occurring between two clinical interviews which reflected a change were then examined to identify those lessons or parts of lessons which contained information relevant to the propositions reflecting that change.

The observational data and the representation of instruction was examined in conjunction with the students' frame matrix to identify the major changes occurring in students' conceptions and the portions of the instruction containing information relevant to these changes. The identification of changes other than those which involve simple addition of new propositions require some means of identifying propositions which are related yet different. To address this need each frame specified certain components of a proposition which were fixed and other parts which could vary. Any proposition which reflected the constant portion of the proposition frame was considered an alternative instantiation of that particular frame.

Phase II Analysis

The results of Phase I were used to guide the Phase II analyses where the transcripts of clinical interviews and relevant portions of lessons were used as primary data sources. Questions were formulated (Lott, 1981, 1982) to provide a focus whereby the data base input could be organized for effective analysis. The results provided an organizing framework which assisted in the description of important classroom, teacher, and student characteristics which could be used to describe relevant patterns of conceptual change.

Selection of Conceptual Changes

In this phase several conceptual changes were selected from those which had been identified in Phase I. These were then further analyzed using the narratives and transcripts of the clinical interviews and portions of important lessons.

There were several issues which guided the further analysis of the selected conceptual changes. In describing conceptual changes attention was directed toward the corresponding identifiable actions and situational constraints as well as the informational, intellectual, and reasoning characteristics of subjects. Insights were sought concerning patterns and regularities of conceptual change which could be used to formulate conjectures for further research.

The procedure began with the examination of the pre-conceptions. The propositional knowledge addressed was then compared with these pre-conceptions and points of cognitive conflict were noted. After the learning experiences leading up to this point, the question raised was "Did the pre-conception answer the question raised by classroom experience?" If it did not, then "Was there any change?" If there was, "What was the level of change?" If there was not, a comparison of student capabilities and task requirements was made.

The following questions were aimed at providing the foundation for making judgements about descriptive representation of conceptual change patterns and the directions for further inquiry. The results were intended to provide bases for describing important classroom, teacher, and student characteristics which could be used to describe relevant patterns.

1) Pre- & Post-Conceptions comparison: comparison of propositional knowledge resolution, literal program analysis, propositional knowledge addressed, student pre-conceptions, and student post-conceptions.
2) Has there been a conceptual change? Is the change of conceptual framework a reformation of cognitive structure?

3) The reformation of cognitive structure may involve variations in organization. What is the change level?

   3.1) Imitating or Assimilation: involves the direct use of beliefs provided by the instructor or by an instructional medium.

   3.2) Modification

   3.3) Translation

   3.4) Transformation: generalization an re-ordering of previously assimilated concepts and principles from the subject matter.

   3.5) Accommodation or Construction: an active search for new information, concepts and principles which are then combined with previous knowledge in essentially novel ways.

4) Classroom task analysis

   4.1) What was student question?

   4.2) What was addressed by activity?

5) Classroom observation

   5.1) Student acts

      5.1.1) What were the tasks performed by the student?

      5.1.2) How does the student organize the elements of instruction?

      5.1.3) How does the student verify the adequacy of the new conceptual structure?

      5.1.4) What kind of systematic course of action did the student plan?

   5.2) Cognitive processing required by learning tasks.

      5.2.1) Recall: storage and retrieval of verbal information.

5.2.2) Discriminate: distinguishing characteristics utilizing intellectual skills.

5.2.3) Develop: relations and principle learning; involves intellectual skills referred to as higher-order rules.

5.2.4) Assess: problem-solving; involves the use of cognitive strategies.

5.3) What were the identifiable actions and situational constraints called for by tasks?

5.4) Propositional knowledge addressed

5.4.1) What information is provided by the task?

5.4.2) What knowledge addressed is not reflected in the literal program analysis? What was the source of the knowledge?

5.5) Classroom interaction

5.6) Teacher acts

5.6.1) What question did the teacher ask?

5.6.2) What was teachers intent?

5.6.3) How does this compare to literal program analysis?

6) Clinical Interview

6.1) Does the student recognize what is being called for?

6.2) How does student interpret the tasks in which he has been engaged?

6.3) What question did student think he/she was answering?

7) Student Manual

7.1) Is there evidence of conceptual change?

7.2) What descriptions and explanations for phenomena encountered were offered?

7.3) What kind of plans were provided or suggested by the student to determine the adequacy of his/her predictions?

The above questions provided a focus whereby the data could be analyzed in an effort to propose implications for curriculum development and teacher education, and conjectures for the direction of further inquiry.

Clinical Interview Transcript Analysis

This aspect of the analysis was aimed at determining if the student recognized what was being called for in the instructional tasks, as well as how he interpreted the tasks in which he was engaged. In addition, interest was directed at exposing how the student interpreted the tasks in which he had been involved; what question the student thought he was answering.

Instructional Transcript Analysis

The procedure for the analysis of classroom discourse involved the delineation of the propositions asserted during the instructional process. This approach to the analysis of discourse provided a framework for drawing upon the transcripts as a source of evidence necessary to discuss the dynamics of conceptual change. In addition, at selected points in the instructional sequence there was the transformation of text or linguistic discourse in the educational setting observed into propositional networks which could then be compared with the literal program and with previous networks.

A student's conceptual framework was inferred from data obtained as students explained scientific phenomena, and developed and tested hypotheses. Within the classroom setting, the phenomenon to be explained was observed within the task environment. Thus, the only unknown was the conceptual framework of the individual. It was therefore possible to infer an individual's conceptual framework from the explanation provided by the student in conjunction with the situational context as observed. This is shown by a schematic diagram along with an example in Figure 6.

The approach has been successfully used for the analysis of text from student manuals and psychomodeling instruments. However, these data sources provide information at the microstructure level. For classroom or interview discourse what is needed is an analysis resulting in the representation of macrostructure. Schank and Abelson (1977) have argued that "the meaning of a text is more than the sum of the meanings of the individual sentences that comprise it" (p. 22). Thus, for the analysis of discourse a theory of semantic representation utilizing the macrostructure of a passage (Kintsch and VanDijk, 1978; Turner and Greene, 1978) was used.

The approach used to analyze discourse was developed after the techniques utilized in cognitive psychology (Kintsch, 1978; Turner and Greene, 1978; Schank and Abelson, 1977) were explored for their appropriateness to this study. The analysis systems of Pines, et al. (1977) "designed for elucidating substantive cognitive content, indicating cognitive differentiation and enabling the comparison of discourse analysis" (p. 74) along with those techniques used by Erlwanger (1974) were modified for the particular needs of this study.

The analysis of discourse provided the information necessary to discuss the dynamics of conceptual change. The limitations found in an earlier study (Lott, 1980) were overcome with the possibility of formulating inferences concerning conceptual framework during the instructional sequence in addition to those inferred pre- and post-instruction on the basis of written psychomodeling instruments.

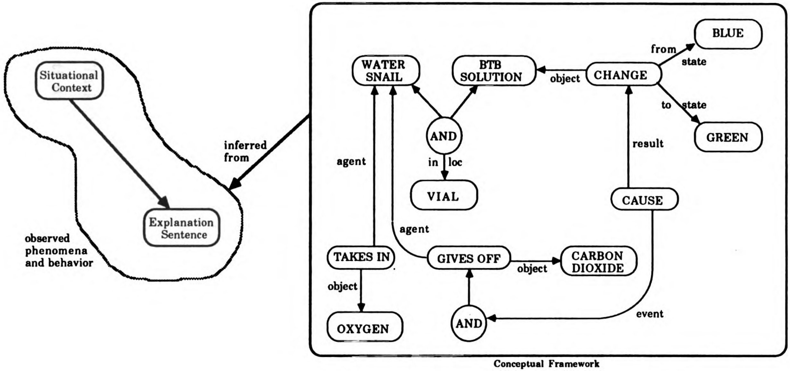


FIGURE 6. Inferential Bridge to Cognitive Structure Representation. (Using the observation of the situational context and the explanation of physical phenomena asserted by the student we can infer the conceptual framework for the student who gave the explanation. In the above case, this began with the transformation of the sentence "The vial contained blue BTB solution and a water snail. The next day the BTB solution was green. It changed because the snail takes in oxygen and gives off carbon dioxide" to a propositional network structure. The inference made in this case, which resulted in the above conceptual representation, was that the student must understand that the change of BTB from blue to green is an indicator of the presence of carbon dioxide.)

CHAPTER 4

RESULTS

The analysis which is described in this chapter evolved from the selection of a set of important changes identified in the Phase I analysis. The data for Phase I, which had been collected in a variety of ways (i.e., observation, interviews, tape recordings), was in the form of words, rather than numbers. The analysis of this data consisted of a sequence of three activities (i.e., data organization and reduction, data display, and the search for changes in students' conceptions). Data organization and reduction consisted of the simplification and transformation of the raw data that appeared in the field notes via editing (i.e., lesson summaries, transcription). An approach for data display (i.e., frame matrix) was then initiated and resulted in the coding of propositions identified as having been asserted by students and teacher. The purpose of Phase I was to identify the major changes that occurred in the target students' conceptions, the period of time during which they occurred and the specific segment of instruction that may have influenced these changes. Propositions obtained from the psychomodeling instrument, clinical interviews or classroom observations were plotted on the frame matrix and compared to identify changes in students' conceptions.

Initially, the changes identified in Phase I were noted for each of the four target students. However, based on the voluminous amounts of data (i.e., 23 pages of Lesson Summaries, one page for each lesson observed; 134 pages of Task Description, which provided a narrative description of classroom activity at the individual task level; 182 pages of Classroom Observation notes; 52 pages of transcription based upon selected lessons from nearly 12 hours of observation over a period of 10 weeks, and nearly 12 pages of field notes from 1 hour of clinical interviews for each target student), only one student was selected for comprehensive analysis. This student (who will be referred to by the pseudonym Ben) was selected on the basis of two criteria: the student had interesting and clear preconceptions and the available data on this student was reasonably complete. Finally, a set of the most important changes of this student were selected for analysis. It is this set of important changes that are described, as a sequence of case studies, in this chapter.

The Phase II analysis took the form of a series of case studies (Lott, 1983a; 1983b; 1983c) with the purpose of identifying features of the instructional events and states of the student's prior conceptual knowledge that might account for the changes which actually occurred. The selection of three conceptual changes identified in Phase I, which were thought to merit further study, was followed by a sequence of analyses; each focusing upon the instructional activities associated with one of the identified conceptual changes in an effort to expose relevant patterns and regularities. These were case studies of an individual student's attempt to make sense of encounters with physical phenomena and classroom discourse during a sequence of learning experiences concerning photosynthesis. This analysis has focused upon the description of classroom occurrences, as well as teacher and student actions, emphasizing those periods of instruction, identified in Phase I, during which the selected changes appeared to have occurred.

Next, several patterns are discussed which yield insights concerning the ways of going wrong when attempting to bring about conceptual change. The focus of the analysis was the finding that the preconception of food for plants was not displaced but was reorganized to include a mechanism for the absorption of food, a substance for making the plant green, and a process for the mixing of food sources. The results of this study provides clear instances, as well as documentation, showing how the preconceptions held by students continued to influence, as might be expected, how they interpreted the natural phenomena which they observed, as well as the information content which they encountered.

It was found that changes in the student's knowledge were influenced by several different kinds of encountered information. Observations of phenomena, as well as abstract ideas presented by the teacher or other students, played an important role in the process of knowledge change. Moreover, the process of knowledge change involved active construction by the student of propositional links not explicitly encountered in instruction.

In addition, questions actually presented by the teacher did not direct students toward the distinctions which were necessary for the interpretation of the observed phenomena. Moreover, student and teacher interaction was found to be influenced by communication difficulties brought about by the use of different interpretive frames by the teacher and student or by the use of a limiting questioning pattern.

Conceptual Changes

Three conceptual changes were found which were thought to merit further study. These consisted of the inclusion of the following in a student conceptual framework:

1) the belief that the cotyledon collects/transmits food to the embryo;
2) the importance of chlorophyll for plants and its relationship to light;

3) the belief that photosynthesis is the "putting together" of materials that are food for plants.

Each of these changes, which were observed in one student who will be referred to as Ben, was the basis for a case study. Each case focused upon the instructional activities associated with one of the identified conceptual changes, each in some way concerned with food for plants and/or plants and light, in an effort to expose relevant patterns and regularities. In each case the student's preconceptions and postconceptions are presented, followed by a look at the student's instructional experiences. It was observed that throughout the period of instruction, the students (including Ben) continued to maintain their preconceptions of food for plants. Given the goals of the unit, this lack of change was also a focus for further analysis.

Prior to instruction Ben viewed food for plants to be various external raw materials including light. The delineation of pre-instructional propositional knowledge provided a reference point from which the extent of the conceptual change could be ascertained and understood. In each case study the central change was an addition to the student's conceptual framework. The analysis attempted to gain insights into how these changes came about.

An important aspect of any analysis of conceptual change is to consider the information content encountered during instruction. A question which provided a focus for further analysis was how the change became integrated into the subject's conceptual framework. In each case, representations of the subject's conceptual framework were examined in an effort to reveal the dynamics over time. Ben's preconceptions are presented, followed by a description of his experiences of instruction. His postconceptions as revealed in the clinical interview following the selected instructional sequence in which the change occurred are then described. This provides the basis for considering the nature and extent of the conceptual change. In an effort to expose relevant patterns and regularities the propositional knowledge addressed within the sequence of learning experiences will be described.

Experience of Instruction

Each of the case studies which follow will provide a description of Ben's conceptual framework over time and his actual instructional experiences. First, a review is made of his conceptual framework prior to the instructional experiences which were the focus of the case study. This is followed by a description of the sequence of lessons and tasks, the propositional knowledge which was asserted by the teacher or students during discussions and procedural tasks and an account of the relevant student and teacher acts observed during the lessons. Then a review is made of Ben's conceptual framework following the instructional experiences which were the focus of the case study and the changes which were identified as the result of the Phase II analysis of classroom observations and clinical interviews. Finally, pre- and post-instruction conceptions reflected in the group data (i.e., data collected for all students using the psychomodeling instrument) are reviewed and compared to Ben's conceptions.

Classroom observation of the occurrences during instruction provided the data base from which student acts, teacher acts, and interaction inherent in the instructional process could be analyzed. This analysis in conjunction with the description of conceptual changes provides a basis for identifying patterns and regularities.

Case 1: Ben's Understanding of Seed Part Functions

This analysis involves an examination of Ben's conceptual framework relevant to the function of the cotyledon, a part of the seed. A discussion of Ben's conceptions pertaining to the propositional knowledge encountered provides several insights concerning Ben's 'web of meaning' as it relates to the function of the cotyledon.

Preconceptions. The information obtained from the frame matrix was used to develop a diagrammatic representation (cf., Norman and Rumelhart, 1975) of his conceptual framework concerning the cotyledon and food for plants (see Figure 7). Ben's frame matrix was based upon the analysis of his psychomodeling instrument, narratives and transcripts from classroom observations, as well as transcripts of his clinical interviews. This diagram illustrates several interesting characteristics of Ben's conceptual framework prior to instruction.

There is evidence that Ben believes that fertilizer is food for plants. However, a closer examination of Ben's first clinical interview shows that his concept of fertilizer is nonconventional. He indicates that fertilizer is food for plants but then elaborates that "seeds absorb fertilizer from sunlight, soil, manufactured fertilizer, decomposed objects, and water." Thus, he believes plants get this food from the soil, light, water, organic matter, and manufactured fertilizer. This constitutes evidence for several alternative propositions which give insight into the interpretive model used by Ben.

Notable by its absence in interview one is any mention of food coming from or being stored in the seed. Although he agreed with this idea when he encountered it on the pretest, he did not bring it up in the interview

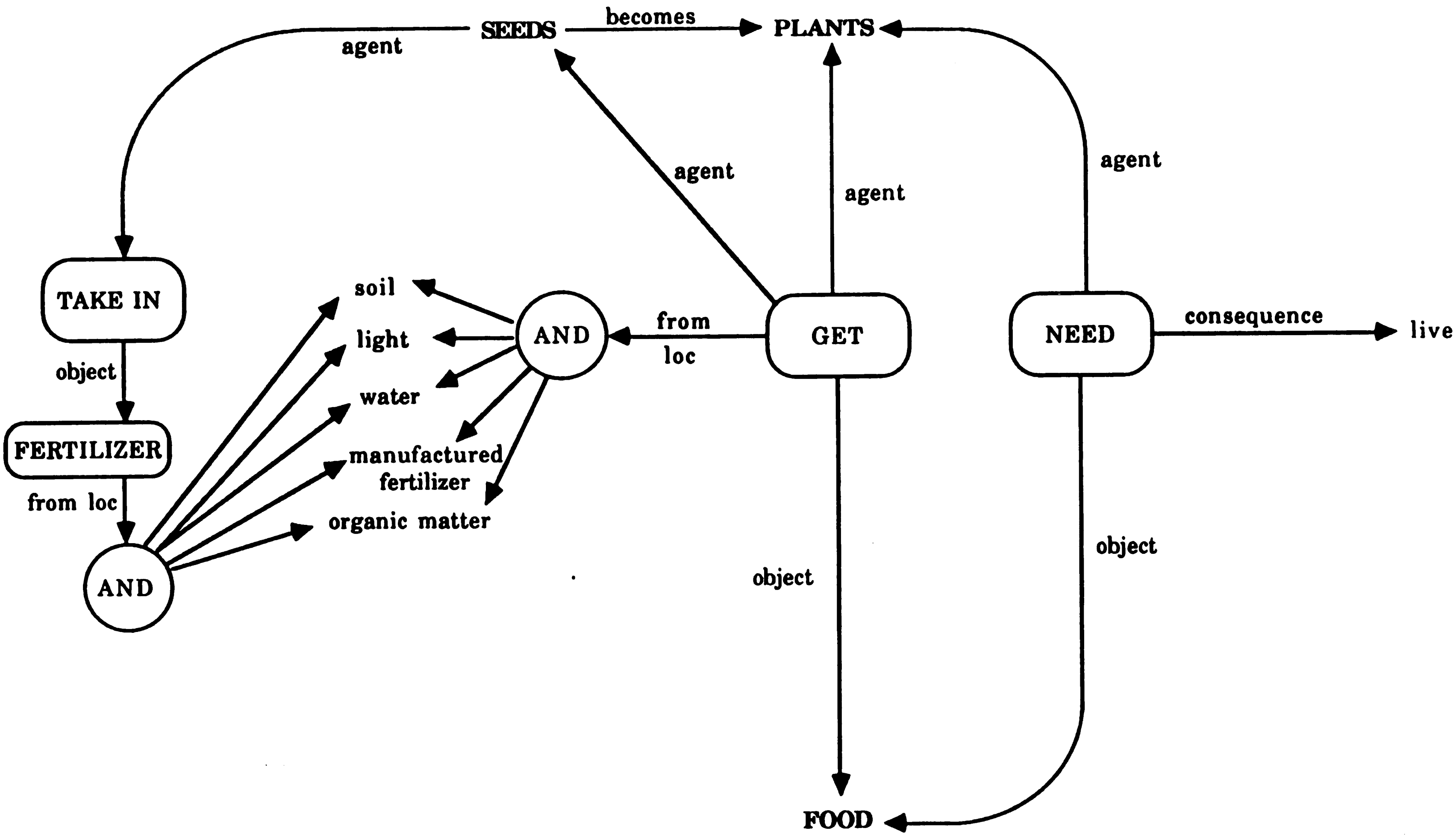


FIGURE 7. SEED PART FUNCTION PRECONCEPTION MAP

despite several opportunities. In addition, when asked to describe the structure of a seed there was no mention of seed parts.

Ben's Experience of Instruction. Those student and teacher acts observed during the period of interest revolved around an experimental arrangement where the seed parts of a bean were placed in a "germination system" to determine which would grow. During a period of several weeks Ben worked with his group observing changes in the seed parts and recording their measurements.

Lesson 4.1 was devoted to setting up the germination system and taking the first measurements of the seed parts. After hearing a teacher presentation concerning the procedures for measuring and recording, the target students decided who would be responsible for each task in caring for the system and recording data. After the first lesson (i.e., 4.1) there followed four lessons during which the seed parts were measured and the results recorded. During each of these lessons there was a discussion in which students had an opportunity to describe changes in the parts. During the third lesson the students were introduced to an averaging method with which they could begin to observe group data patterns. During the fourth lesson the discussions began to involve students in interpretive acts. The technique for averaging data points was used during lesson 4.4 but was not used thereafter.

Early in Lesson 4.3 as the target group began the measurement of each seed part someone indicates the cotyledon has shrunk, but Ben measures again and finds no shrinkage; others disagree. During the discussion a student indicates that while the cotyledon alone has not grown the embryo with the cotyledon had. Ben indicates that the embryo had grown "wingy" things.

It was during Lesson 4.3 that the teacher conducted a discussion concerning what an average is. Ben watched as the teacher demonstrates the technique to be used with the class chart data for finding an average. He became involved in the discussion and watched as another student used the concept of a balance point to find an average. Several in the class asked for another demonstration of the averaging technique which had been described by the teacher, and several students inquired as to the purpose of this procedure. Later, during Lesson 4.4 while the teacher was using the averaging technique for each seed part, a student indicated that he was not sure of the task being done. The teacher attempted to clarify the procedure.

Lesson 4.4 continued the process of measuring and recording. Growth is observed and during the measurement of the cotyledon with embryo attached Ben exclaims that the cotyledon has shrunk. During a classroom discussion in Lesson 4.4 Ben encountered, as the result of a hypothesis verbalized by a student, the information that the cotyledon provides food for the plant. This was offered by the student in the context of a question in reference to the embryo and whether the cotyledon would grow. The student response was that the cotyledon would not grow, it would "give it (i.e., the embryo) food to grow."

After the average length for each seed part was found, a discussion was initiated aimed at determining which seed part had grown the fastest. Ben stated that the cotyledon had. Kathy, another student in Ben's group, indicated that the cotyledon and embryo had; this received general agreement from the class. The question was asked as to what parts had not grown. Ben indicated that the cotyledon had shrunk. This apparent inconsistency in Ben's observations was not addressed by the teacher. It was not clear if he was referring to the cotyledon alone or the cotyledon and embryo. Some in the class suggest that the observation of cotyledon shrinkage was due to measurement error. There was general agreement that the cotyledon alone had not grown. The teacher then asked about the embryo and Gloria, another student in Ben's group, indicated that it had grown.

At the beginning of Lesson 4.5 the teacher announced that they would measure each part and then discuss their predictions concerning what each seed part does for the growing plant. Ben immediately observed a change; the embryo and cotyledon has grown. The cotyledon was found to have shrunk while the whole bean remained the same. The teacher asks why the embryo alone had shrunk to which Ben replied that it was probably dying. During the discussion which followed the measurement of seed parts, and in reference to the embryo and cotyledon, Ben described how it had grown and Walt replied that the embryo had stopped growing because it didn't have anymore food. Ben then suggested that it needed fertilizer.

As the discussion continued the teacher asks that they think about their predictions. Ben states that his prediction was that the cotyledon would protect the seed until it sprouted. Vickie indicated that her prediction was that the cotyledon would feed the embryo. The teacher responded by rephrasing and saying "the cotyledon acts like the mother and feeds the embryo, that's what made it grow."

During Lessons 4.4 through 4.7 the proposition that the cotyledon provides food for the embryo was affirmed several times. These lessons were intended to reveal to the student that the embryo only grows when attached to the cotyledon. Moreover, their observation that as the embryo grows the attached cotyledon shrinks was intended to lead to support for the idea that the function of the cotyledon is to provide food for the young plant. An examination of the frame matrix and the supporting transcription of classroom discourse provides evidence that on several occasions students hypothesized or inferred from their observations that the cotyledon provides food for the young plant.

During Lessons 4.4 through 4.7 Ben encountered the idea that the cotyledon provides food for the embryo. However, this idea would not be in conflict with his preconception concerning food for plants. His preconception of food for plants, asserted during clinical interview one, was that it consists of external materials which are "absorbed" by the plant. All of these sources except soil are present during the germination experiment. The observation of the embryo growth when attached to a cotyledon necessitates only that he add to his conceptual framework an object, the cotyledon, through which food is absorbed.

Observations which were made during Lesson 4.3 through 4.6 did not necessitate any fundamental change in Ben's conception of food. His preconception of food for plants was that raw materials were absorbed by the plant. The following transcript excerpt from clinical interview one provides an insight into this conception.

> Ben: The seeds need fertilizer for them to grow.
> I: Could you tell me a little more about how they get this fertilizer?
> Ben: They absorb it from the sun rays and from the soil and other things.
> I: Could you give me an idea, you say other things, what these other things might be?
> Ben: Well, they would be manufactured fertilizer, decomposed objects, such as dead animals or something, and water.

Two of the raw materials referred to, light and water, were present in the germination system experiment. Thus, the observations during the experiment were apparently not problematic and did not challenge the "central concepts" (Posner, et al., 1982) of Ben's conceptual framework.

However, the experiences of chapter four have resulted in the internalization of information content which is internally consistent. Ben could therefore explain his observations through the addition to his framework of an object which could absorb and transfer food to the growing plant. Thus, the cotyledon 'providing food' was assimilated as the proposition "the cotyledon (does) (collect/transmit) food for the young plant" which results in a reorganization of Ben's concept of food.

Lesson 4.7 marks the culmination of the germination system experiment. Several students reported the results of their group's germination system. The teacher referred to each of the experimental conditions in an effort to organize the responses. However, there were instances when she referred to the parts of a seed creating some ambiguity in relation to the condition referenced in the student response. The teacher consistently referred to seed parts rather than experimental conditions, increasing the potential for confusion (e.g., was a reference being made to the cotyledon alone, or the cotyledon attached to the embryo). After each group had responded the teacher changed the focus of the discussion by asking why the cotyledon had shrunk. This continued the ambiguity of reference as to whether the teacher was alluding to the attached cotyledon as a part of a condition, or the condition consisting of a separate cotyledon.

The discussion continued with the teacher asking which part would grow into the plant. After it was established that the embryo would grow into the plant the teacher asked what the function of the cotyledon is. Student responses were in what became a "ping-pong" discussion (cf., Mary Budd Rowe, 1969); there was no probing on the part of the teacher to determine the underlying meaning of responses. Students were saying the cotyledon gives the embryo food. The teacher stated that the cotyledon is the food.

Postconceptions. An examination of Ben's postconception provides some evidence that he has internalized a theoretical proposition concerned with the function of the cotyledon. Ben's interpretation of his observations and the assertions of the teacher and other students during Lessons 4.4 through 4.7 is revealed by his statement, during Clinical Interview 2, that "the embryo with the one cotyledon stores extra water for the embryo (inaudible) the germination discs it gets water from the cotyledon." It can be inferred from this statement that he views the cotyledon as a "collector" of water for the embryo.

A review of Ben's postconceptions in contrast to his preconceptions reveals that he has experienced a conceptual change. This change of conceptual framework seems to have involved a transformation (cf., Lott, 1982) of cognitive structure whereby new concepts and principles were combined with previous knowledge. The concepts present in the preconception representation have been retained yet with the addition of a new concept, the cotyledon, the relationships have been changed.

A diagram representing Ben's knowledge of plants and food after Lesson 4.7 based upon the second clinical interview is given in Figure 8. Ben's original framework is represented by the solid line while the additions and changes are shown by dashed lines. For example, in the original diagram there was no mention of the parts of a seed or their function. The diagram highlights the modification of this belief.

The representation in Figure 8 provides evidence that Ben's belief system has expanded as the result of observations during Chapter 4 to include the cotyledon as a source of food. However, a review of the second

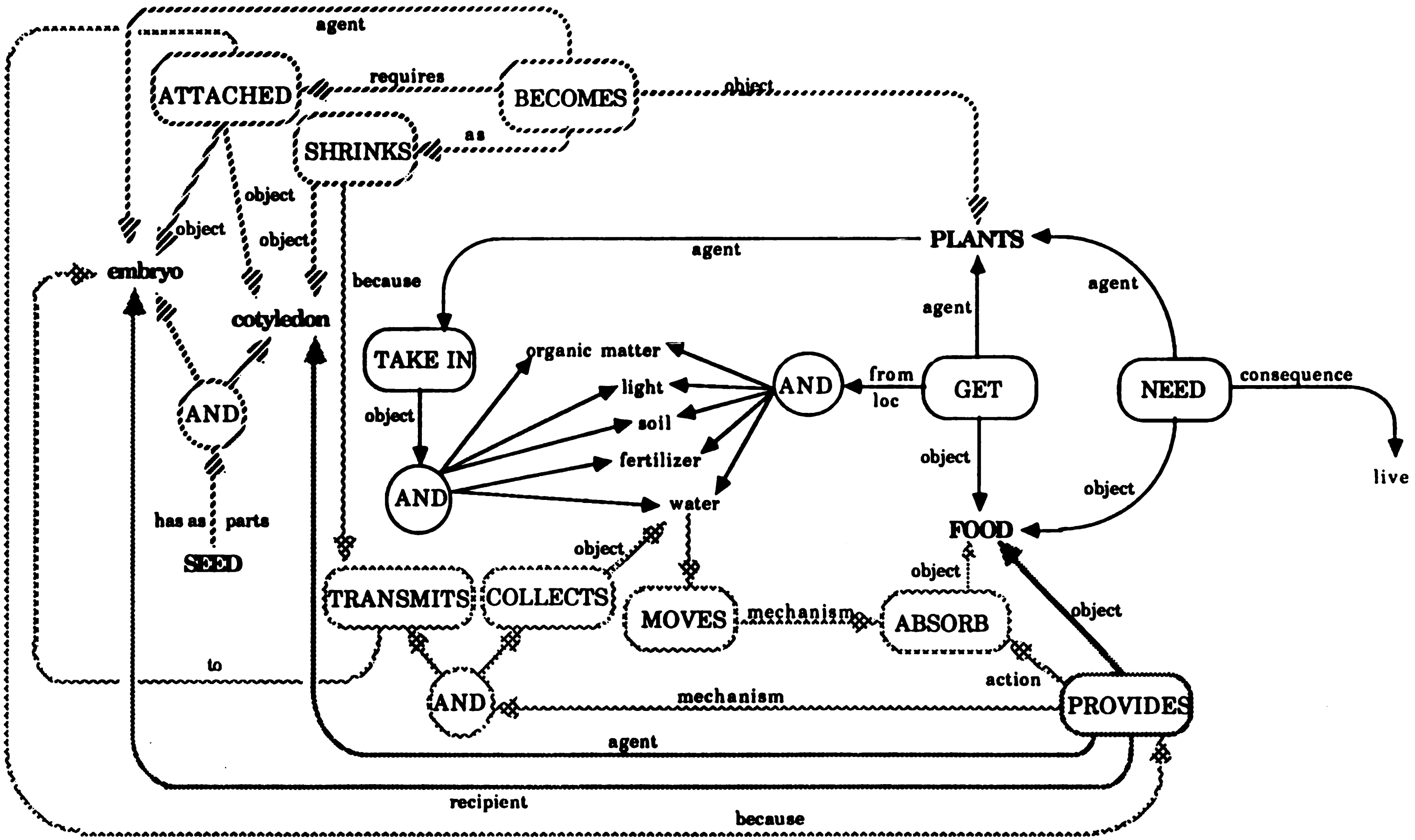


FIGURE 8. SEED PART FUNCTION POSTCONCEPTION MAP.

clinical interview indicates that here is an inconsistent meaning for a common concept. The evidence for this is his assertion that the "cotyledon would store water for the embryo"; giving some indication that he views the cotyledon as a mechanism for feeding the embryo, rather than as consisting of or being food. A goal conception that the cotyledon is food is implied in the literal program while Ben's conception is that the cotyledon contains food (i.e., water) that it gives, or transmits, to the embryo. The following transcript from the second clinical interview provides a view of his belief concerning the importance of water.

I: You have mentioned water several times. What do you think water does?
Ben: Well, it is part of the feeding process for the plant or the seeds.

Ben previously indicated a belief that food for plants is 'fertilizer' taken in from several forms of matter. He now conceptualizes food acquisition for plants to include the cotyledon as a source as well. He has assimilated the idea that the cotyledon provides food or is a source of food in terms of the cotyledon being a mechanism for collecting and transmitting food for the young plant. His ideas of what the food is remained unchanged.

Patterns of Change Reflected in Group Data. The students' pre- and post-instruction conceptions for this topic show that prior to instruction 63% viewed raw materials as food for plants (see Table 2), while after instruction 20% continued to believe that only raw materials are food for plants. The group data further shows that while many student's put it together like Ben, a few did not. The evidence suggests that only a few students comprehend this as the instructional program would have it. This shows, based upon the post-instruction administration of the psychomodeling

TABLE 2.

ALTERNATIVE CONCEPTIONS CONCERNING FOOD FOR PLANTS
(n=21)

VALUE	LABEL	PRE-TEST	POST-TEST
1	Something plants make (raw materials not mentioned).	0	24
2	Water (only).	15	0
3	Water, air and light (only).	0	5
4	Raw materials (other combinations including water).	33	10
5	Fertilizer, minerals and/or soil.	5	5
6	Raw materials (other combinations not including water).	10	0
7	Raw materials and cotyledon seed.	0	19
8	Something made and raw materials.	0	0
9	Unsure	19	15
10	Tells why needed (only)	10	5
11	Cotyledon or seed (only)	0	10
0	Other	10	15

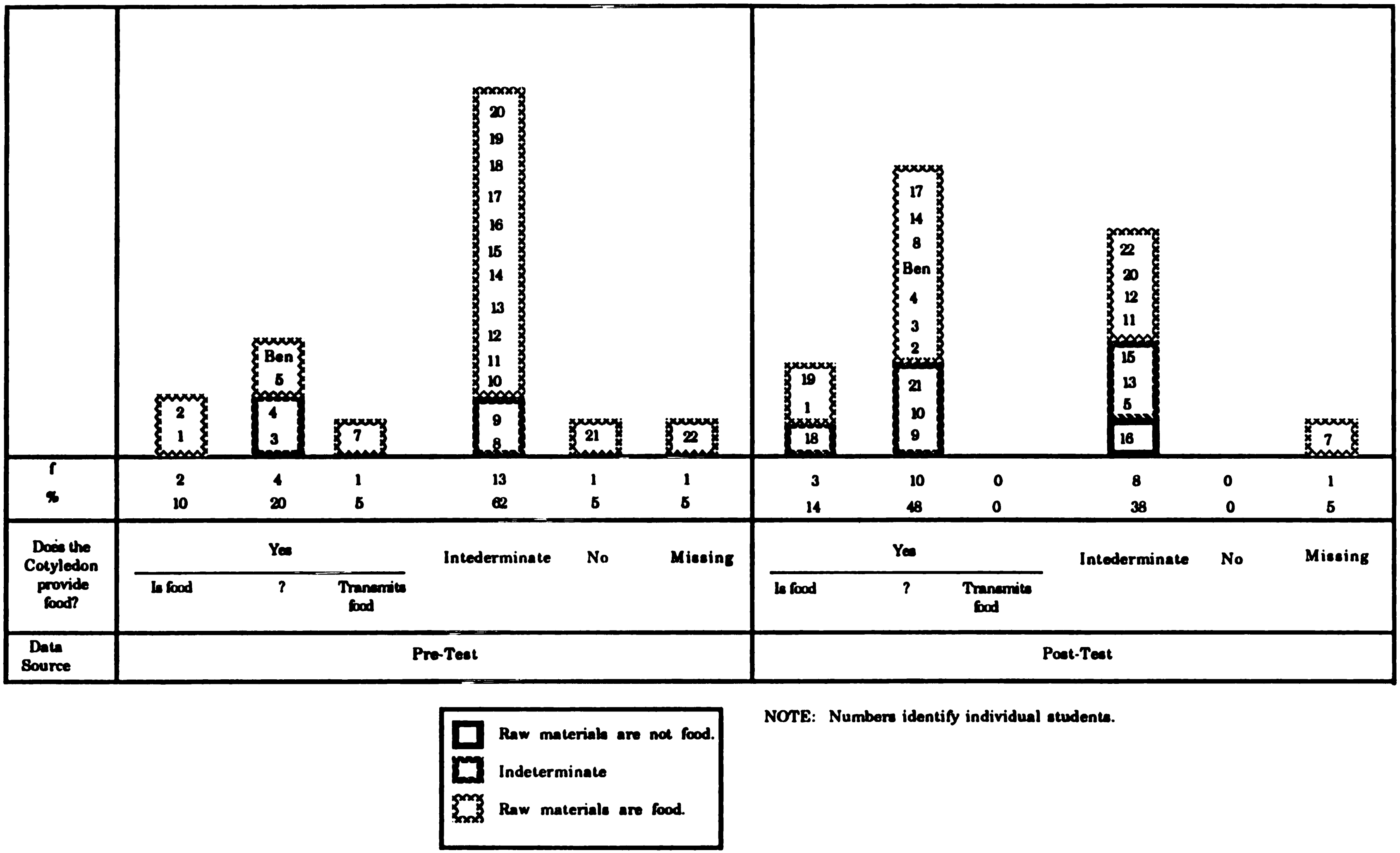
instrument, that of the ten students (45%) who assert, like Ben, that the cotyledon does provide food for the embryo to grow, only three (14%) gave evidence of believing that it is the food (see Figure 9). The data supports the view that Ben's interpretations were not that different from those of other students. The data indicates that of those students who held the idea that the cotyledon provides food, sixty-six percent continued to view raw materials (water, soil, air, etc.) as also being food for plants (see Table 2).

Case 2: Ben's Concept of Plants and Light

The change of interest in this case is the addition of chlorophyll to Ben's conceptual framework. The analysis seeks to determine how this change came about; how the concept of chlorophyll became integrated into Ben's conceptual framework. Also of interest in this study are the conjectures concerning his view of the consequences of the presence or absence of chlorophyll and its function in the living processes of plants.

Preconceptions. Prior to his exposure to the germination system Ben refers to seeds need for sunlight. In addition, he indicated that seeds need fertilizer for them to grow. Elaborating further he stated that "they absorb it from the sun rays and from the soil and other things." He explains, during the first clinical interview, that these other things are "manufactured fertilizer, decomposed objects, such as dead animals or something, and water." The important insight at this point is that Ben believes plants get something from these materials. In this instance he refers to fertilizer, however, he indicates by his reply that it is different from commercial fertilizer. In his view the raw materials are a source of "nutrients" (see Figure 10).

Ben's preconceptions of what constitutes food for plants involved external raw materials. These materials (water, light, etc.) are the sources of



NOTE: Numbers identify individual students.

FIGURE 9. ALTERNATIVE VIEWS OF THE FUNCTION OF THE COTYLEDON.

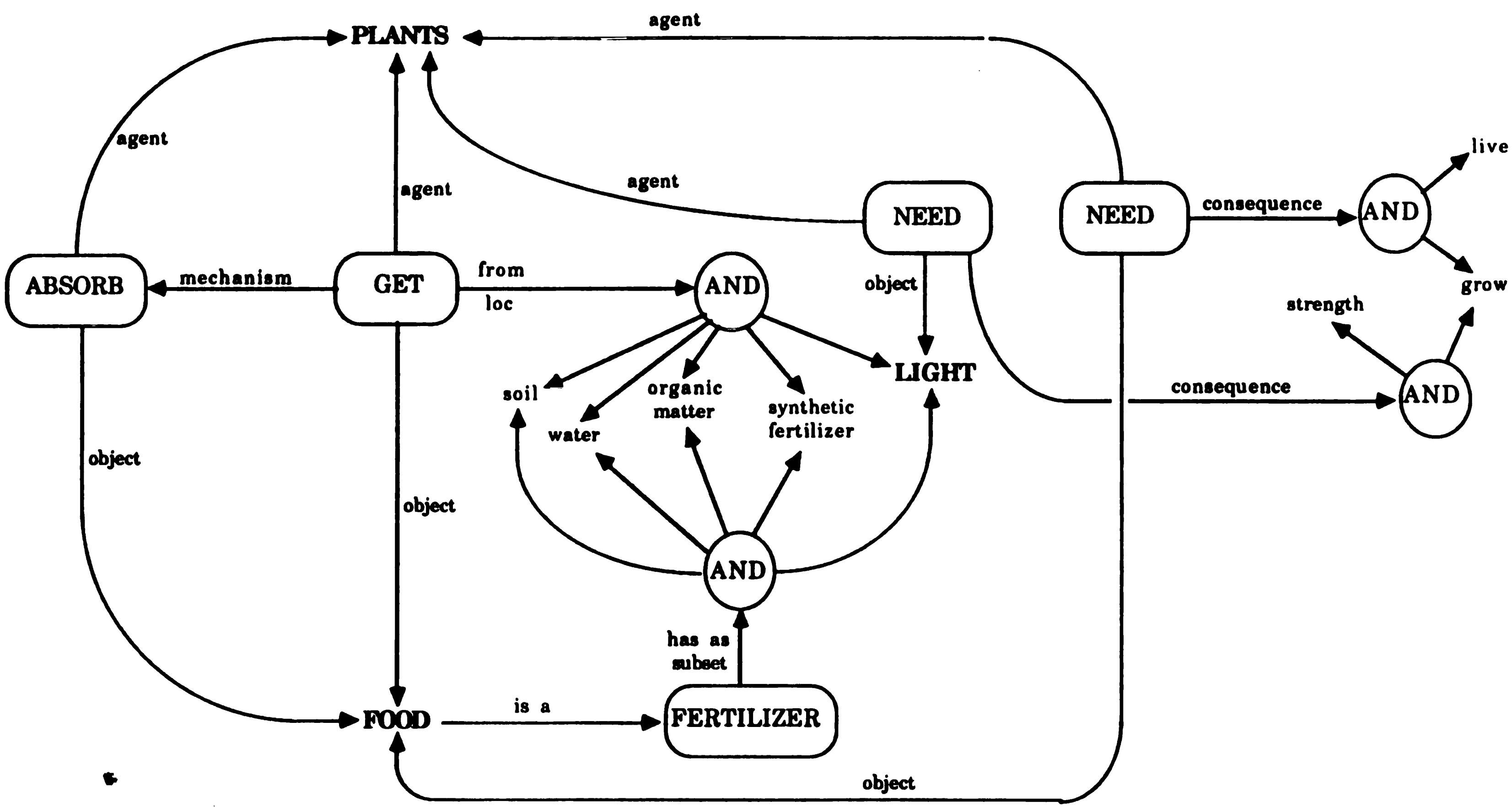


FIGURE 10. BEN'S PLANTS AND LIGHT PRECONCEPTION MAP.

something ("fertilizer" or "nutrients") used by the plant to live and grow. These materials are taken in or as Ben refers to it "absorbed." The plants need in terms of light is viewed in terms of consequences; the presence of light results in strength and growth. There is no evidence of the function of light in bringing about these consequences.

Ben's Experience of Instruction. During instruction in chapter five Ben observed grass grown in the light and dark. Early in Lesson 5.1, prior to the set-up of the experiment, a discussion was conducted around the question "do plants need light to grow?" During the discussion Ben remarked that:

> They won't grow as extensively if they are in the dark. They'll still get the food they need to grow ... sunlight will give them more food and they will grow bigger.

Although another student conjectured that plants do need light to grow, Ben suggested that plants in the dark get food from water and fertilizer whereas in the light they get their food from light in addition to water and fertilizer.

Several days following the initial planting of grass seeds, but prior to any observations of growth, the teacher organized a discussion concerning seed part functions. Following a brief discussion about the embryo, the teacher asked "What about the cotyledon?" She indicated that she was aware that some of the students had different ideas and would like to hear what they were. The students who she called upon stated that "it (i.e., the cotyledon) gives food to the embryo." The teacher responded by saying "O.K." and then stating "It is food to the embryo." There was then a discussion revolving around the idea of the cotyledon as a mechanism for getting food. During this exchange of ideas a student suggested that the cotyledon stores food. The teacher then pointed out that the cotyledon shrivels and gets smaller. It was at this point that Ben stated that the cotyledon gives food to the embryo and another student commented that the cotyledon absorbs the food.

It was during the discussion in Lesson 5.3, following the observation of the plants and recording of results, that Ben encountered the information that the cotyledon helps plants begin to grow in the dark. This reference to the cotyledon and plant growth in the dark came as the students were discussing the results of their observations. Several students observed that plants in the dark begin to grow more than those in the light, while others indicated that their plants in the light grew more than those in the dark. It was during the closing remarks of this lesson that the teacher made the observation that "plants in the dark have grown as as well or better than the ones in the light."

The observation that plants in the dark turn yellow was made in lesson 5.4 when the students took the plants out of the closet where they had been kept in the dark. The task before the students was to measure the height of the plants. It was during this lesson that some plants from each group were switched, (i.e., plants in the light were moved to the dark and plants in the dark were moved to the light). This provided a four-plot experimental design in which plants were measured and the results recorded over a period of several weeks.

Ben's focus on the height during Lesson 5.4 led him to observe that "plants in the dark grow taller than those in the light." He concluded that "plants in the dark grew well because they got nutrients and the food they needed from other sources than the sun." Although a student stated during the discussion that plants in the dark get nutrients from the soil and water, but the sun gives extra nutrients, there is no evidence that Ben incorporated it into his conceptual framework at this point. A conjecture put forth by Ben during this lesson was that "plants switched from the dark to the light will begin to turn green." He appears to have at this point become aware of the importance of the presence of light to the color of plants being green (see Figure 11). Ben viewed light as an alternative source of nutrients, as providing "extra" nutrients, which may have laid the groundwork for what came in lesson 5.5.

At the beginning of the task in Lesson 5.5 where students were to discuss their observations and make interpretations, the teacher focused the discussion on plants started in the light and kept in the light. After the discussion shifted to plants taken from the dark and placed in the light, a student suggested that plants which had been switched from the dark to the light turned green because of the sun. Ben suggested that "the sun gives it the extra food and nutrients it needs to get back the normal color of any other plant."

Ben had come to believe in a connection between the color of plants and the presence of light based upon the empirical evidence observed during the observation phase of this and earlier lessons. To this point, Ben had made no reference to chlorophyll. After Ben's comment John offered the view that plants produce chlorophyll. John suggested that the plant can not produce chlorophyll without the sun, and that the chlorophyll is the green. The teacher repeats John's assertion later in the discussion and this provides another point at which Ben can consider the alternatives. In an interview following this lesson Ben gives evidence of a belief in the making of chlorophyll as a mechanism by which plants remain green in light (see

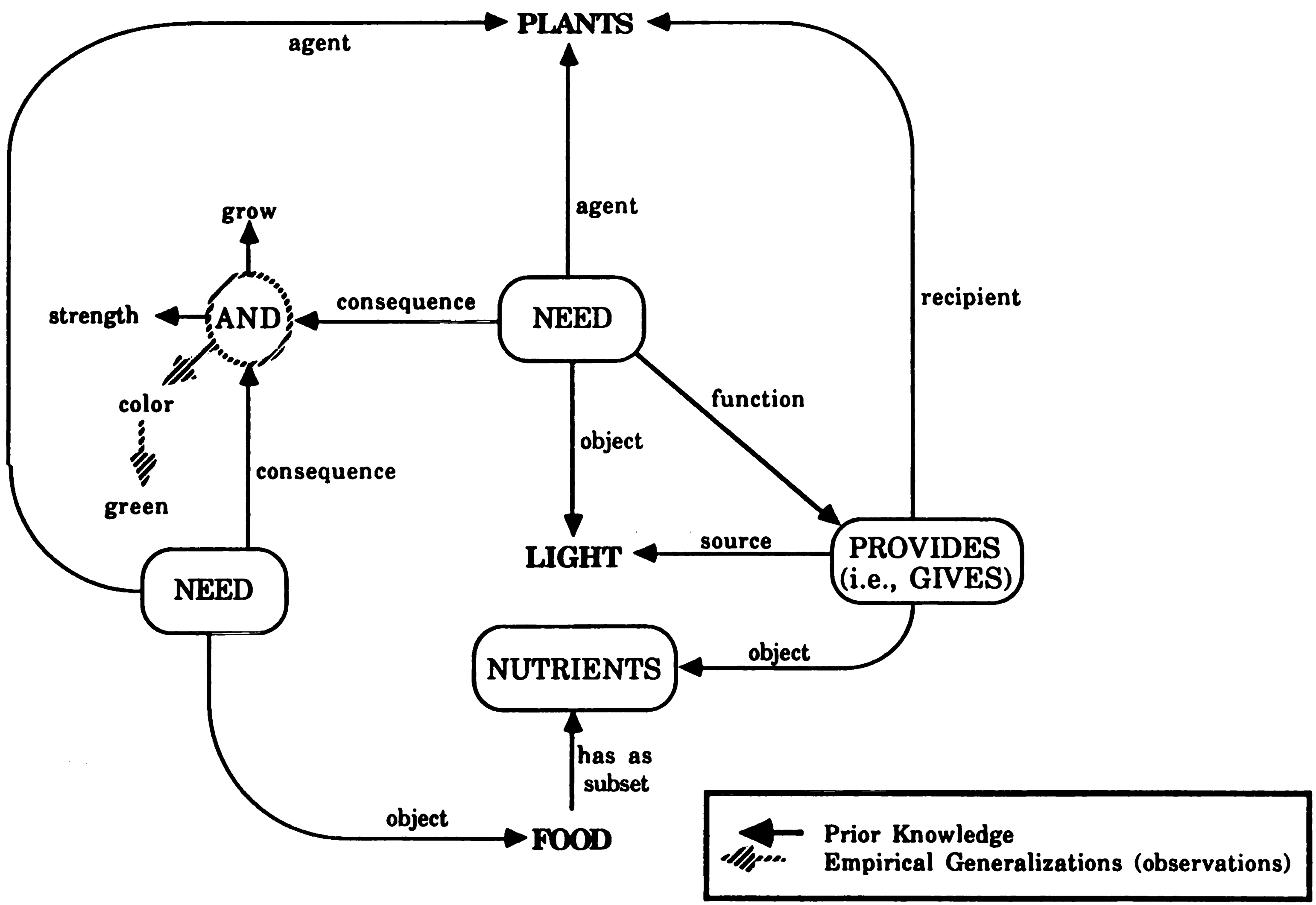


FIGURE 11. PRE-LESSON 5.5 PLANTS AND LIGHT CONCEPTION MAP

Figure 12). Thus, Ben apparently integrated this knowledge into his previous structure.

At this point it became evident that Ben realized plants need chlorophyll to be green. This is an important feature of this intermediate state of knowledge. This may have been the result of his encounter with the empirical evidence that plants need light to be green in conjunction with information content provided by other students, and reiterated by the teacher, in Lesson 5.5. With this relationship firmly developed he was able to make the inference that if chlorophyll is necessary for plants to be green then the light must be influential in its production by the plant.

It was the relationship developed in Lesson 5.5 which leads to the inclusion of chlorophyll in Ben's framework. The empirical evidence that plants in the dark are not green and plants in the light are green along with the reference to chlorophyll by John leads to the assertion, during clinical interview three, that chlorophyll makes plants green. With the relationship of light to color he then apparently inferred the relationship between light and chlorophyll.

Thus, the idea of the plants being green and its relationship to light developed from empirical evidence. The inclusion of chlorophyll was the result of an assertion by a student during instruction which gave him the basis for an explanation in the form of a mechanism which resolved his sense making process.

During Lesson 5.6 while the students were involved in a discussion of their observations, Ben encountered the finding that plants moved from the dark to the light had changed from yellow to green. His observations during this period led him to conclude that plants kept in the dark will remain the same. In his view, they could not get much yellower than they already

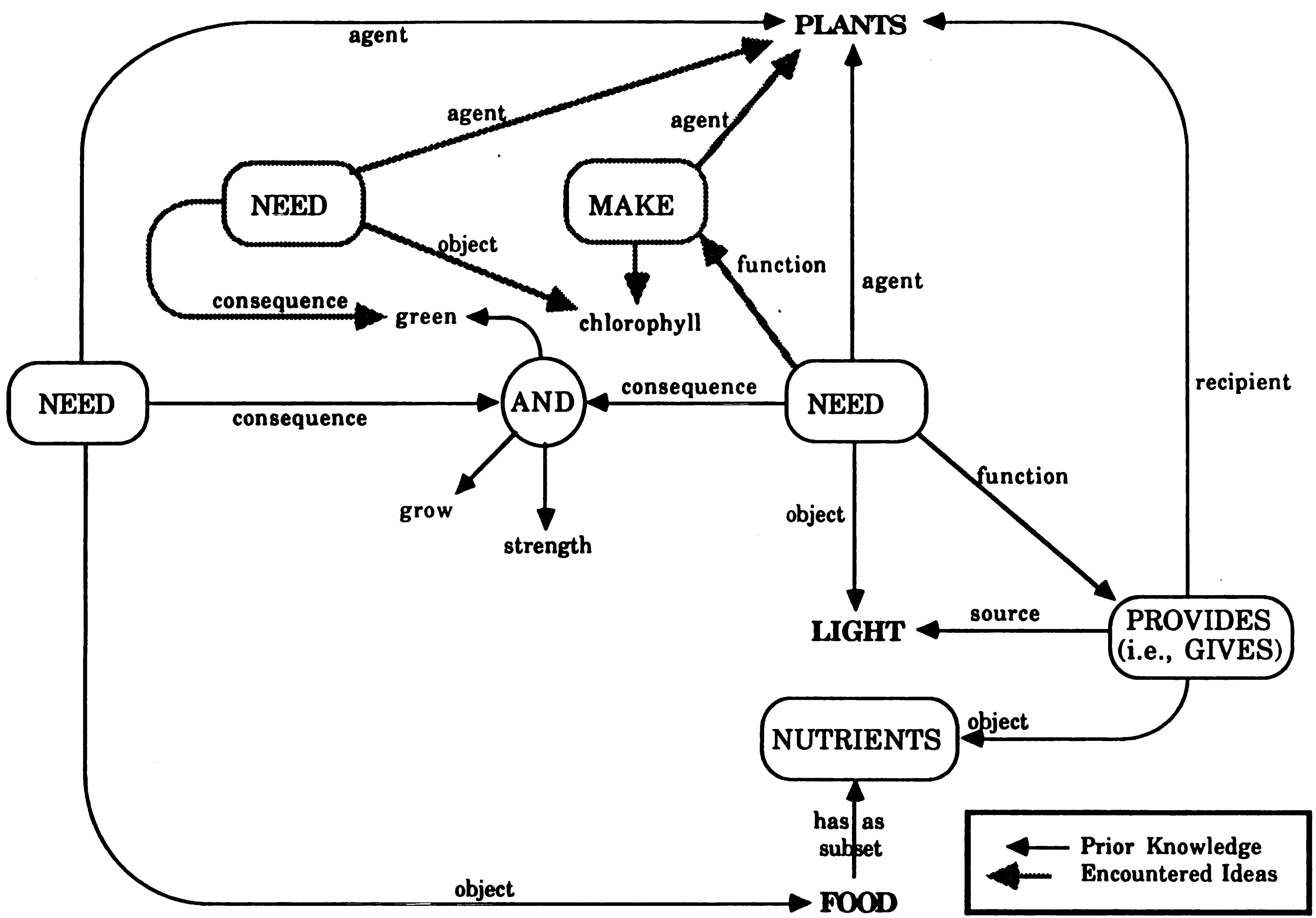


FIGURE 12. POST-LESSON 5.5 PLANTS AND LIGHT CONCEPTION MAP

were. His assertion provides evidence that at this point he does not see the lack of chlorophyll as being life threatening.

The discussion during Lesson 5.10, the last devoted to describing the results of the four-plot experiment, was concerned with the condition of plants in the dark as opposed to those in the light. As the students described the results of their experiment, a student proposed that plants in the dark were losing food because plants make food out of sunlight. Early in the next task, the purpose of which was the interpretation of results, Ben stated that "light gives the plant the food it needs to produce the chlorophyll." Another student then said "light gives the plant nourishment and makes it green, and green looks more healthy." The outcome of this discussion was that plants in the light are green and healthy while plants in the dark are yellow.

Additional statements made during this discussion suggests that while several students had incorporated light into their conception of food for plants, misconceptions continued to persist. While one student stated that "plants turn light into food," another indicated that "plants need light because light feeds them."

Postconceptions. Throughout the period involving Chapter 5 Ben continued to maintain his preconception of food for plants as water, fertilizer, and light. The major change in Ben's knowledge was the addition of chlorophyll to the conceptual framework. It is near the end of Chapter 5 that Ben asserted the importance of chlorophyll for plants. He viewed chlorophyll as a green substance that plants make and which then makes the plant green. While consequences were referred to; processes were not specified when given the opportunity. During the fourth clinical interview he was asked to explain how the light makes the plant make chlorophyll. Ben responded:

> I don't know, how it helps it make it. All I know is it needs the light to make the chlorophyll."

Although a student verbalized the belief, during Lesson 5.5, that "plants in the dark will soon die," it was not reflected in Ben's post-Lesson 5.5 conception (see Figure 12), but was after Lesson 5.10 (see Figure 13). It appears that Ben's observation of his group's set-up did not, however, lead him to infer this since both of the set-ups observed by Ben's group were in the light. Apparently, it was teacher and student comments as well as any observation made of the plants of other groups during task 3 of Lesson 5.6 and task 2 of Lesson 5.10 which influenced this change.

Early in Clinical Interview 4, which followed Lesson 6.2, it became clear that Ben views light as a source of nutrients. While he indicates that these nutrients are used to produce chlorophyll it is not clear as to whether he believes chlorophyll has any function beyond making the plant green.

However, the knowledge asserted near the end of instruction is reflected in Ben's new affirmation of chlorophyll as what makes plants green. This is further elaborated as he indicates the plants need for chlorophyll and in terms of consequences an awareness of the importance of light for a plant's color and to sustain its life. Ben states that light is important because:

> ... it gives the plants the extra nutrients it needs to produce the chlorophyll and without the chlorophyll the stems will die out because of lack of food, so the whole plant will die because the grass is all stems.

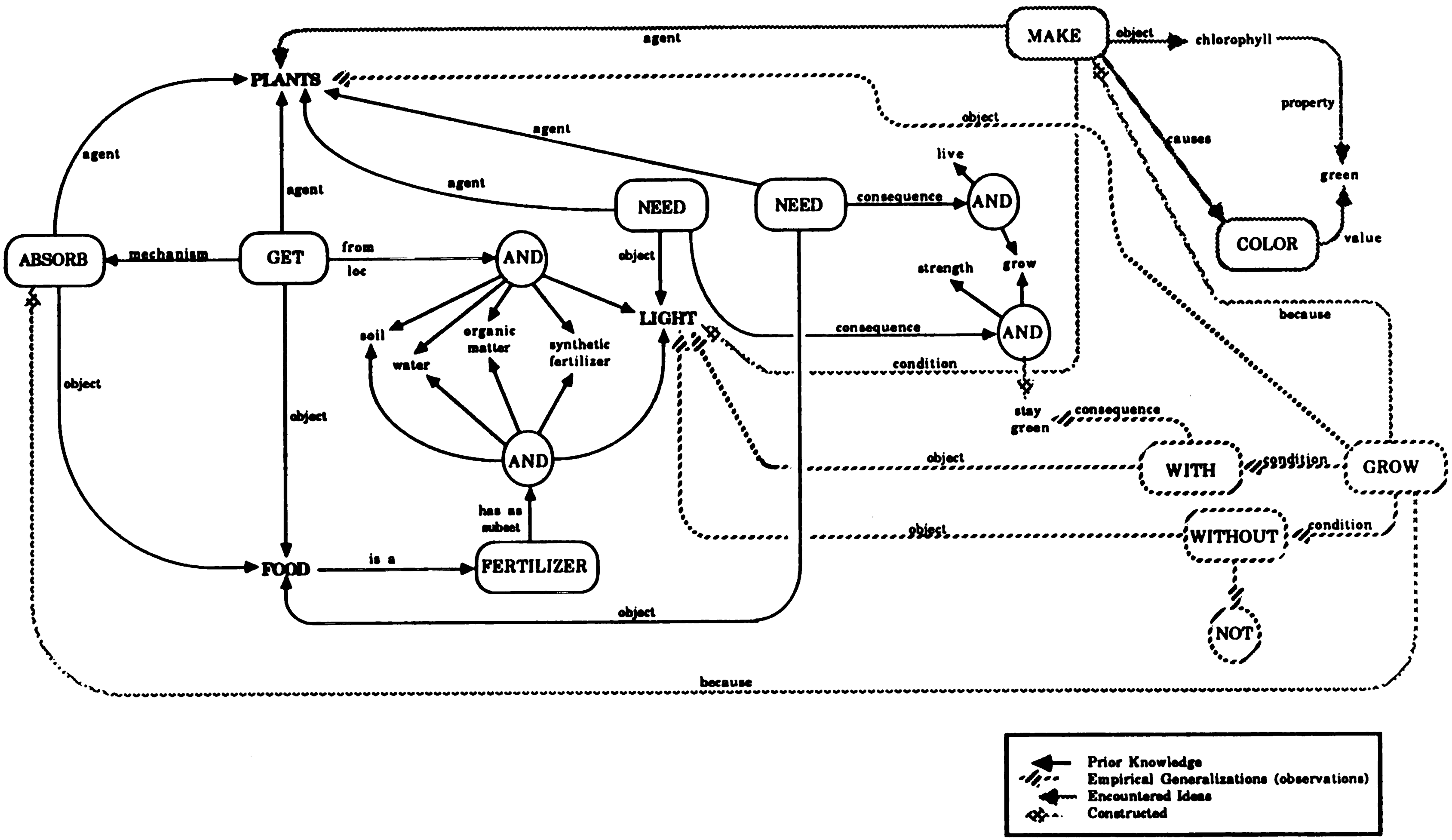


FIGURE 13. PLANTS AND LIGHT POSTCONCEPTION MAP

He goes on to state that soil is important because:

> ... it has nutrients to start it to sprout but it can't continue to grow without the light because it has to make chlorophyll for it to keep its color and stay alive.

He views plants having food as contingent upon the presence of chlorophyll which is dependent upon the plant having light. Moreover, it is the chlorophyll which gives the plant its color and upon which it is dependent in order to stay alive. However, this is the only reference to food as anything other than raw materials or something absorbed from them.

Patterns of Change Reflected in Group Data. The group data shows a shifting of conceptions. Fifty percent of the students who prior to instruction believed plants would not grow in the dark changed their conception to believing light is desirable, but that plants would grow in the light or dark (see Figure 14). Ben was unsure whether plants would grow in the dark prior to instruction. The qualitative data does not reflect a view on the part of Ben that light is essential for plant growth until after the fifth lesson of Chapter 5. Unlike the group Ben became committed to plants need for light in order to grow (i.e., live).

It is interesting to note that forty percent of those who prior to instruction believed light to be essential to live and grow changed their belief system and asserted that light was not needed by the plant (see Figure 15), while thirty-three percent were found after instruction to believe that light was needed for the health and color of the plant. These students' thinking actually moved further from the goal conception for the unit.

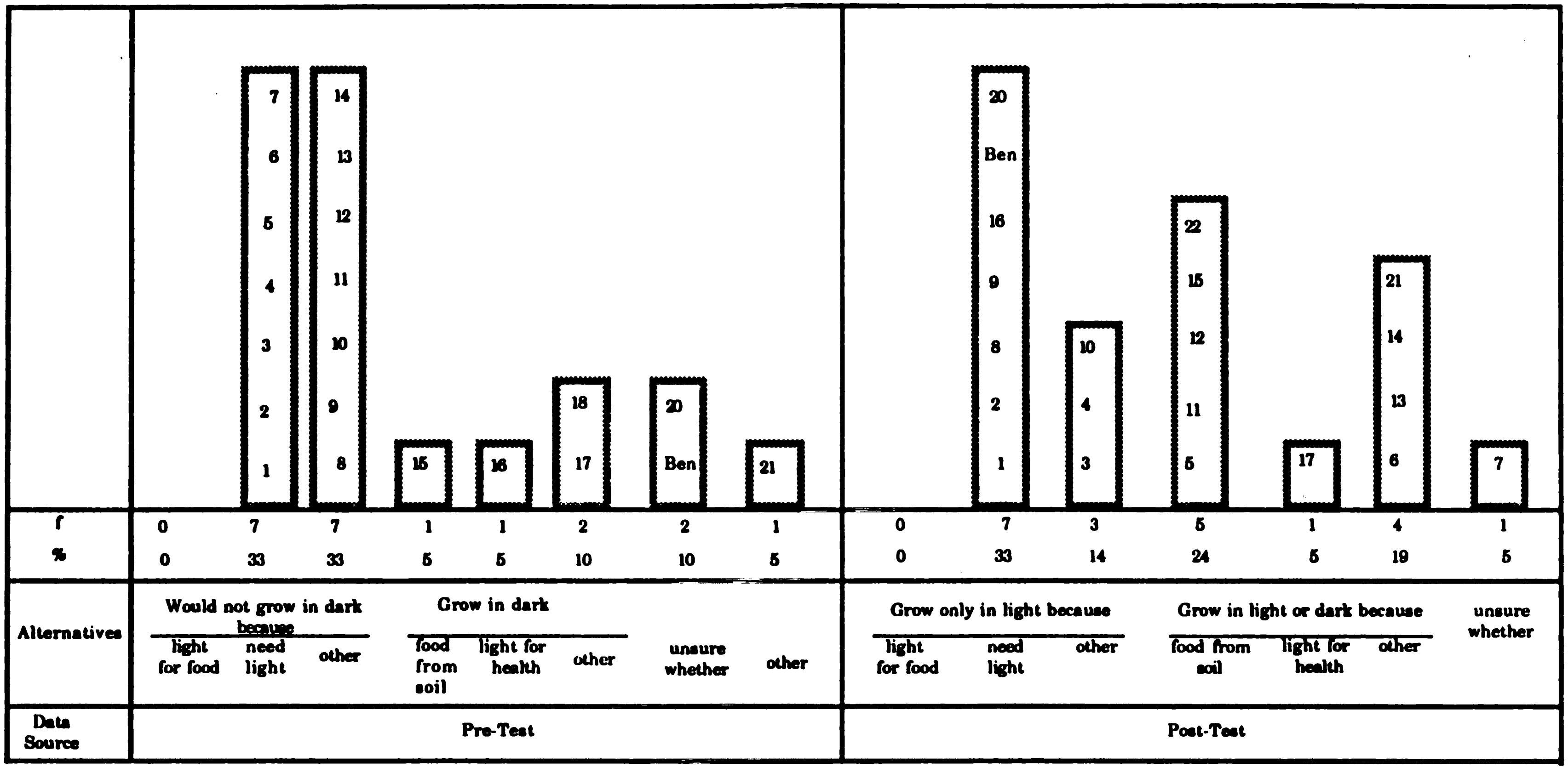


FIGURE 14. ALTERNATIVE EXPLANATIONS OF PLANT GROWTH IN THE DARK.

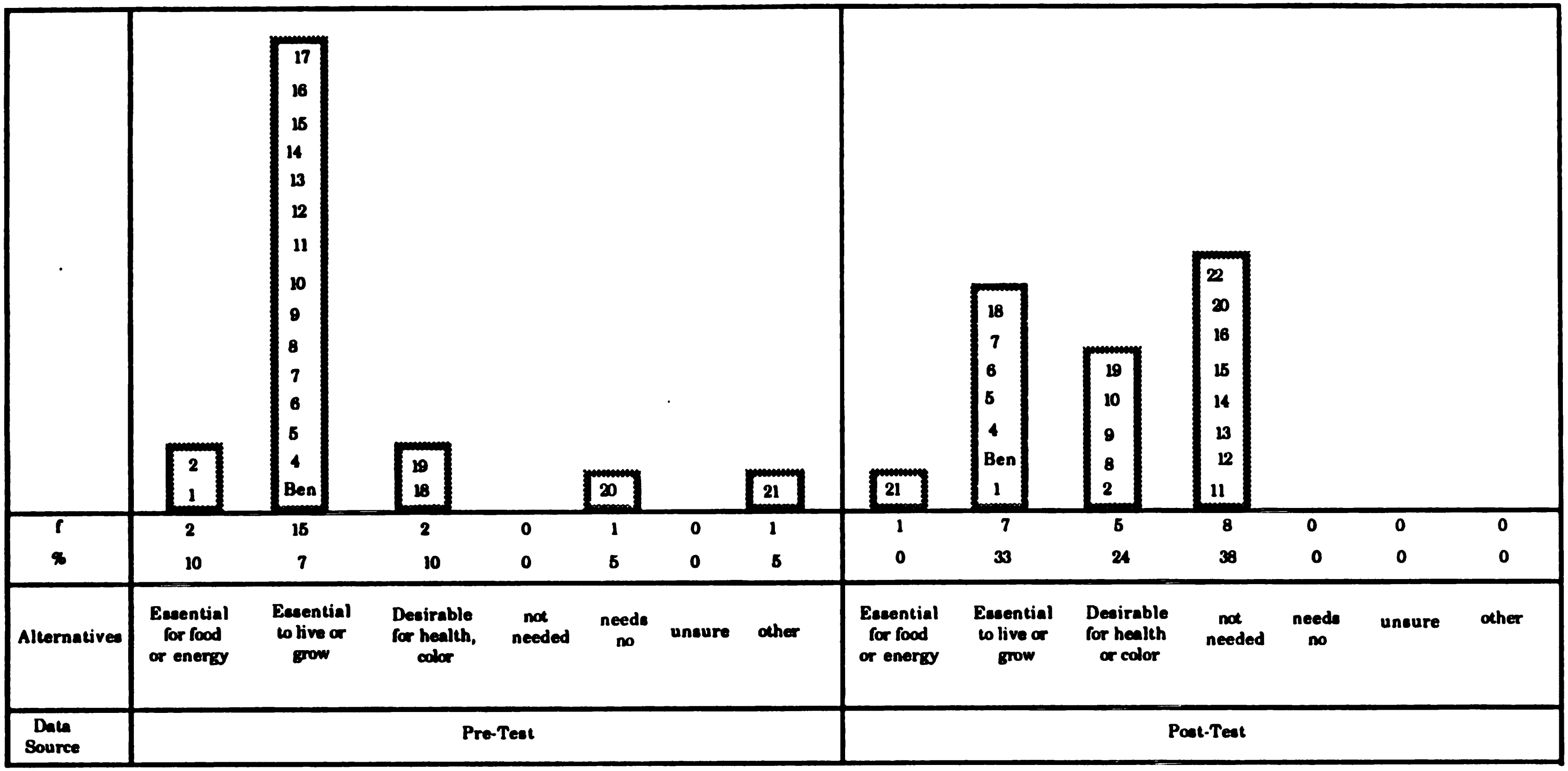


FIGURE 15. ALTERNATIVE VIEWS OF PLANTS NEED FOR LIGHT.

Case 3: Ben's Interpretation of Photosynthesis

The change in Ben's knowledge which was of interest in this case was the addition of photosynthesis to his conceptual framework. Although he asserted the importance of photosynthesis near the end of Chapter 6, the evidence for this change and his assertions concerning the concept directed attention toward his apparent idiosyncratic concept of the nature of photosynthesis.

Preconceptions. Evidence for Ben's preconceptions were obtained from the clinical interview three which preceded the "invention" of photosynthesis as well as instruction for Chapter 6, and page ten from the student manual in which students predicted the outcome of the bean plant experiment which was set-up following Lesson 5.5. Note that this preconception precedes the postconception of Case 2 as a result of the initial lesson concerned with photosynthesis being conducted prior to the final lesson included in Case 2.

Ben's conceptual framework at this point seemed to be built around the importance of light (see Figure 16). His conception of light is that it provides plants with nutrients; it is a source of food. There is no evidence at this point that he believes plants make their food. Food for plants is something external, something taken in, and consists of nutrients in the air, soil, light, and water taken in by the plant.

Prior to beginning the activities of Chapter 6 Ben asserted that the function of light is to provide the food nutrients to make the chlorophyll. He also believed that plants need chlorophyll to be green. He believes that to be green plants must produce chlorophyll and this requires taking in nutrients from ultraviolet rays. This reference to ultraviolet rays occurred

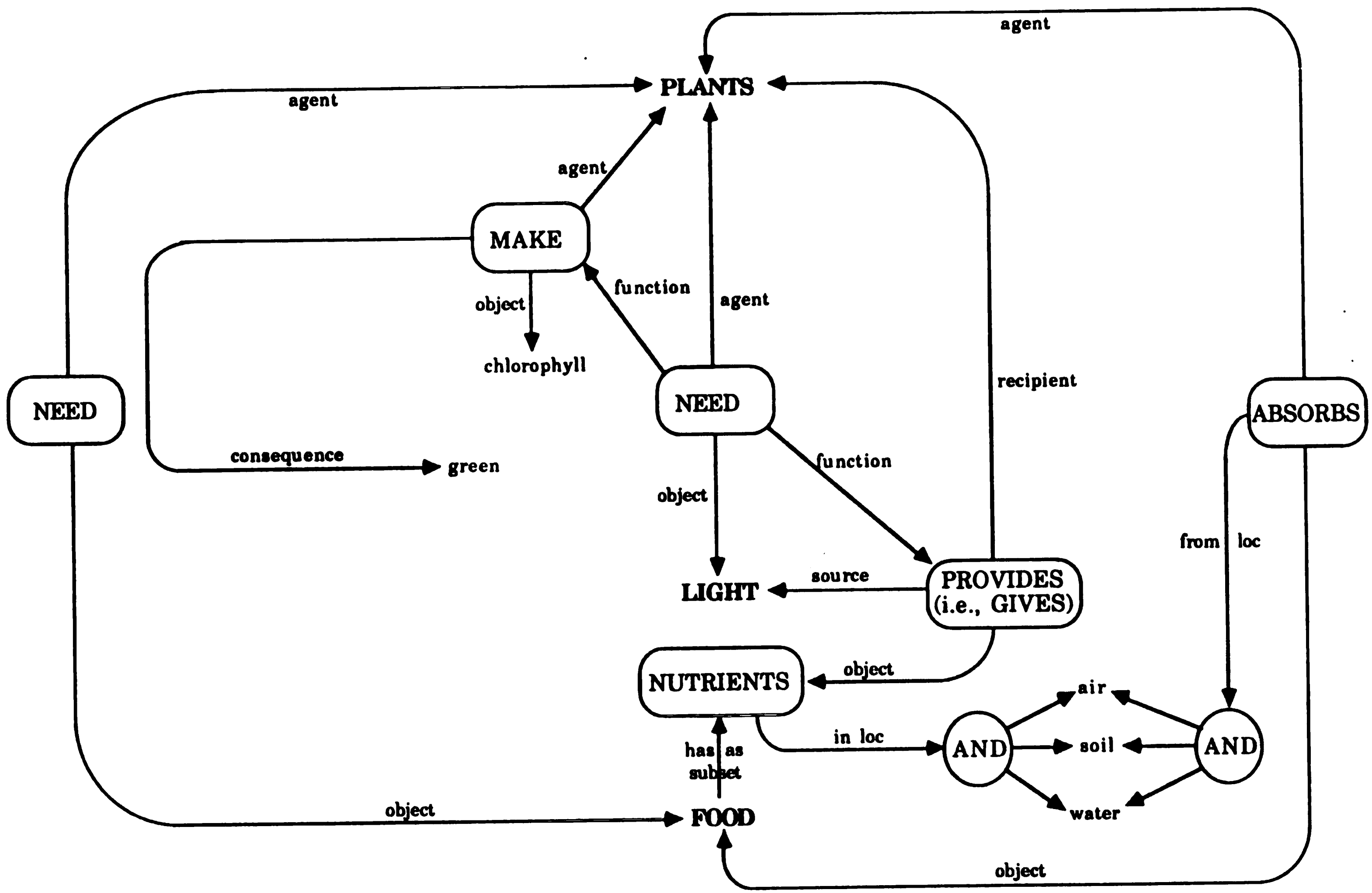


FIGURE 16. PLANTS AND FOOD PRECONCEPTION MAP

during Clinical Interview 3 when in reference to his belief that plants in the dark would grow he stated that:

> ... it isn't the light that makes it grow, it's the ultraviolet sources in the sunlight that makes it grow and makes the chlorophyll ... it isn't the light its the ultraviolet rays that contain the nutrients to help the plants to produce chlorophyll.

He apparently thought that the plants in the dark could somehow obtain ultraviolet rays (unfortunately this was not probed further). The key point seems to be that sunlight is important in plants production of chlorophyll.

The evidence indicates that Ben did not see a lack of chlorophyll as preventing plants from living. He believes, based upon assertions during Clinical Interview 3, that grass plants which were started in the dark and remained in the dark will:

> ... keep growing except they're going to stay yellowish-white. And they're just going to keep growing like normal plants except they're going to be a different color.

It appears at this point that Ben sees chlorophyll as something which makes the plant green but that it is not the material which makes the plant grow.

In summary, it appears that at this point Ben believes that the function of light is the provision of nutrients which are needed to produce chlorophyll. At this point he also asserts the importance of light to the color of the plant. Here he also asserts that the consequence of the presence of chlorophyll is the plant being green.

Ben's Experience of Instruction. During task four of Lesson 5.10 the teacher stated that "plants use the energy from sunlight with the water and air ... to produce food." She then went on to "invent" the concept of photosynthesis; a step suggested in the Teachers Guide where the teacher provides the children with an idea (e.g., concept) for interpreting what they had observed. In this case the teacher suggested to the students that plants use the energy from sunlight with the water and air to produce food. Reference was then made to this process being called photosynthesis and the teacher then interpreted the derivation of the word by stating "photo means light" and "synthesis means putting together." She then asked a student to interpret what she had said. The student she selected to respond indicated that "photosynthesis means putting the air, water, and light together to make food."

She then moved on to clarify the relationship of plants and food by suggesting to the students that "plants have two sources of food." She asked what these two sources might be to which a student replied "plants two sources of food are light and the cotyledon." During this exchange, in response to a statement made by the teacher, Ben indicates that "the making and putting together light, air, and the water is called photosynthesis." Here photosynthesis seems to be viewed as the <u>mixture</u> of these raw materials.

During instruction in chapter six Ben observed a four-plot experiment using bean plants. This involved bean plants in the light with and without cotyledons, and bean plants in the dark with and without cotyledons. The plants were measured and the results recorded over a period of several weeks.

The intent of this experiment was to have the students apply the photosynthesis concept as an explanation of the phenomena they observed. The observations and discussions provided for a reinforcement of the ideas which were introduced previously (i.e., the cotyledon is food for the young plant and plants make their food using the process of photosynthesis).

Prior to having the students set up the experiment the teacher initiated a discussion aimed at reviewing the results of earlier experiments. The teacher asks that they discuss the assertion that "the embryo grows when the cotyledon is attached to it." Ben agrees as does most of the class. Although this had been asserted by students in Lesson 4.7, this was the first assertion of this point by the teacher.

It was during Lesson 6.2 of the instructional sequence that "to live" becomes a consequence of needing light for Ben. Previously (in task 3 of Lesson 5.6 during the grass experiment) he had asserted that plants in the dark would be different than those in the light only in color. As the discussion continued in Lesson 6.2 a student stated that "bean plants without a cotyledon will grow in the light because it will have photosynthesis." Another student went on to say that "plants without cotyledons placed in the dark will die." Ben was seen to agree with the assertion as did most class.

At this point in the instructional sequence Ben continued to believe that soil provides nutrients the plant needs to live. His view that light is an important factor which influences plant growth has been expanded; without light the plants will eventually die. When asked his beliefs, during Clinical Interview 4, concerning what would happen to grass planted and then covered with a pail, Ben stated that "it would die off because of lack of light." Further into the discussion he states that light is important because:

> ... it gives the plants the extra nutrients it needs to produce the chlorophyll and without the chlorophyll the stems will die out because of lack of food, ...

Ben's interpretive mental system concerning light and plants includes the belief that the function of light is to provide the nutrients needed in the production of chlorophyll, which results in the plant being green. At this point his view of the importance of light for the plant is built around color and the view that without chlorophyll the plant will die (see Figure 17).

The discussion in Clinical Interview 4 aimed at probing Ben's hypothesis concerning the experimental conditions of Chapter 6 exposed a change in his conception of the function of the cotyledon. He believes that the beans that are in the dark but still have the cotyledons will "keep growing until the cotyledon is all used up and then they are going to start to die". His explanation for this view is that:

> ...the cotyledon is the food that starts it to grow and after it has started growing it has to use all of the other resources, but they don't get all of the resources they need in the dark, so they die.

The above provides evidence that Ben now considers light to be important for plant life. Plants in his view, must have light in addition to other resources in order to live. He also asserts at this point that the cotyledon <u>is</u> food for the plant.

It is apparent that while he believes plants make chlorophyll, food for plants continues to be something they take in. There is no evidence that he believes plants make their food, however, there is evidence that he has internalized a concept of photosynthesis as a mixture of light, air, and water.

Following the measurement task during Lesson 6.4, the teacher requested that students respond to the question of which plants in the light had made the most growth. As the students discussed their observations, Ben indicated that the "plants in the light without the cotyledon have shown the most growth." Another student made the conjecture that "bean plants with the cotyledon grow the most because the cotyledon gives the plant food." The discussion continued with the teacher not attempting to probe

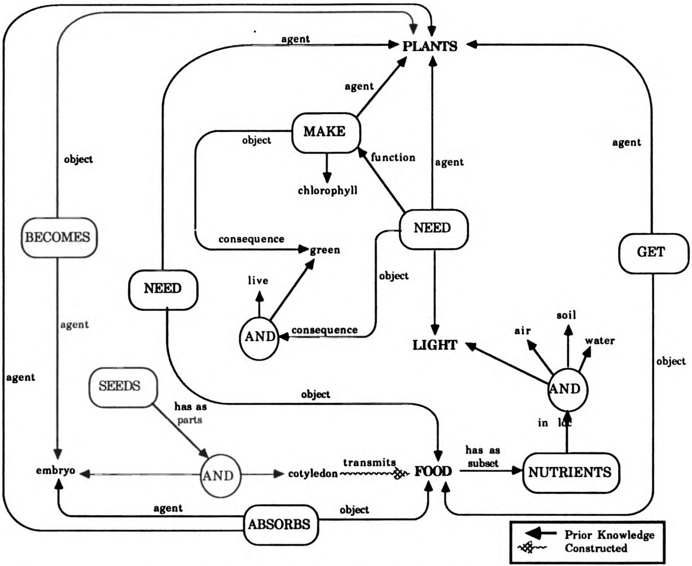


FIGURE 17. INTERMEDIATE PLANTS AND FOOD CONCEPT MAP. (This concept map is based upon Ben's statements during Clinical Interview 4 as well as those statements made prior to lesson 6.4 and following lesson 5.10.)

student responses and focusing the attention of the students upon plants in light. Despite several opportunities for the comparison of conflicting student responses or of experimental conditions in the light, the conflicting responses were not challenged and the differing experimental conditions were not pursued. This form of discussion resulted in a "collection" of responses with no focus and a tendency to lead to confusion.

At one point in the discussion the teacher did ask the students for an explanation in terms of "why have plants with the cotyledon made more growth?" This was followed by a student stating that "plants with the cotyledon in the light have double food or have more food. The bean plants without the cotyledon only have photosynthesis." However, she did not pursue this student's underlying rationale nor the perception of the other students regarding this view of food and plants.

The teacher then turned attention to the plants in the dark; pursuing this in the same manner as the discussion about plant growth in the light. As the discussion shifted a student hypothesized that plants in the dark without the cotyledon had not grown as much because they had no source of food. Another student, in response to a question posed by the teacher, asserts that "plants must be exposed to some light in order to grow."

The investigation continued with the measuring and recording of plant height. During a discussion in Lesson 6.6 Ben encountered the assertion that bean plants in the light have photosynthesis so they do not need to keep the cotyledon. This provides evidence that, for this student, there is a realization that for photosynthesis you must have light. As the discussion continues another student asserts that "the cotyledon feeds the embryo and after the cotyledon is gone the plant then gets the food from the sun, air, and water."

It is during the next lesson, as the students measure and record the height of their bean plants, that Ben states that those "in the light without the cotyledon will grow because without the cotyledon it would use photosynthesis." After the students had completed the task of recording their measurements, the teacher asked that they describe what they had seen. Many in the classroom agreed with one student's statement that "plants in the light are the healthier and are growing stronger." Another student observed that the "bean plants in the dark with the cotyledon have got some height while the ones without the cotyledon did not grow much."

The discussion which followed focused upon the interpretation of the observations. While one student suggested that plants in the dark will eventually die because they have no light, Ben states that plants get food from the soil. In addition, he asserts that soil has food in it and the plant takes it out. However, when the teacher states that plants have two sources of food, Ben responds by saying that the two sources of food for the plant are the cotyledon and photosynthesis. Ben picks up on the teachers interpretation (i.e., "sources of food") and refers to an object and a process; an object in terms of the cotyledon and a process in terms of the action of mixing nutrients. The teacher then comments that "soil provides for deficiencies by providing minerals and vitamins plants need to grow," to which Ben agreed.

The completion of the bean plant experiment was followed by the teacher asking the students to complete the brainteaser in their student manual. The student manual page, with a drawing of a bat flying into a dark and apparently abandoned mine, posed the questions, "If the bat flew into the mine and several seeds fell out of its fur and began to grow in the moist mine, would the plants survive?" and "Explain why?" The purpose of this activity was to give the teacher an opportunity to ascertain the level of understanding the students had of the concept of photosynthesis.

Once the students had completed the task the teacher initiated a discussion. During this discussion a student suggested that "plants at the back of the cave will not have light and will not live because they do not have photosynthesis." As the discussion continued another student stated that "light is just an extra part of photosynthesis." Yet another student responded that "even if plants need photosynthesis, two out of three isn't bad. This is another appearance of the mixture view with some clarification of consequences. An analogy is a tossed salad without tomatos; it's better with tomatos, but still nourishing without them.

Following the statement by a fellow classmate that "plants in the cave will grow but will not be healthy", Ben again acknowledged that plants will die without light when he said "plants in the dark will grow but will not survive." It was shortly after this that the teacher initiated a discussion of plant needs. During this discussion it was asserted by one student that plants need photosynthesis to live. Another student followed by saying that "plants need light, water, and air to live." When Ben followed this statement by asserting that air is part of photosynthesis, he appeared to once again be using a mixture view of photosynthesis rather than the process view.

Postconceptions. The knowledge asserted following the completion of Chapter 6 reflects Ben's new affirmation of photosynthesis as a source of food for the plant. This is further elaborated as he indicates during Clinical Interview 6 that photosynthesis is the "getting together" of food sources for the plant. He states:

> It is water, air, and light all going in and getting together, cause photo means light and synthesis means combining air and water, so when you do that all three of those are food sources for plants. When it is in the dark it can't have photosynthesis because it only has air and water.

It is a process in which the food sources for the plant are combined; an action involving the mixing of food sources. The evidence indicates that he seems to believe that photosynthesis is a mixture of water, air, and light; that it is "stuff," not a process involving change (see Figure 18).

Ben continues to believe food for plants is something they take in. What is taken in is nutrients from the soil, air, water and light. He also continues to believe that the role of light is to provide plants with the extra nutrients needed to make chlorophyll. He views plants as needing chlorophyll to be green and to live. This has followed out of the empirical evidence that plants need light to be green.

The central change for Ben during chapter six was his inclusion of photosynthesis in his conceptual framework. While the concept of photosynthesis was "invented" at the conclusion of chapter five following the grass experiment; it was not until Lesson 6.7 that Ben began to use the concept to explain phenomena he had observed. His view of food for plants continued throughout this period to be formed around raw materials (water, fertilizer, air, and light) which contain nutrients that plants take in. However, attention is focused on Ben's idiosyncratic conception of the nature of photosynthesis.

His addition of photosynthesis seems to involve a view similar to that which he developed for the cotyledon feeding the plant; a mechanism for transmitting food. He does not view plants as making their food, but rather as engaging in a taking in process and "putting together"; there is no

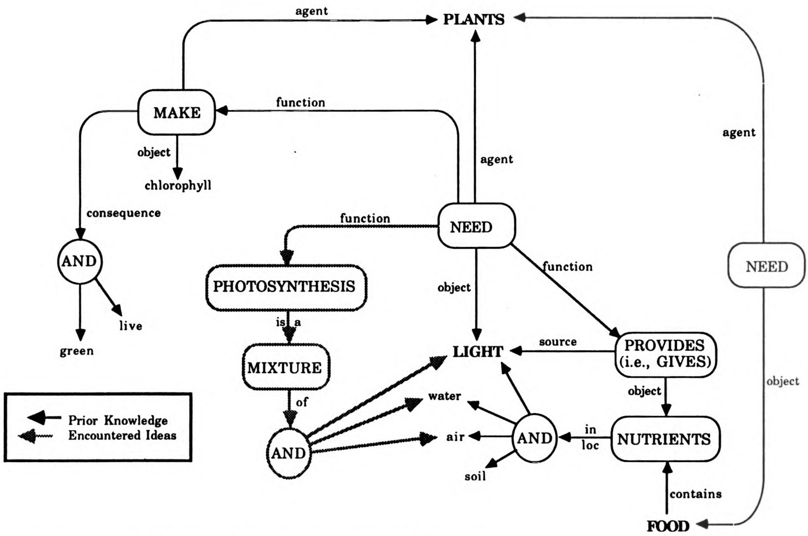


FIGURE 18. POST-INSTRUCTION CONCEPT MAP. (This concept map is based upon Ben's statements during Clinical Interview 6, those statements made during and following lesson 6.7, as well as the results of the post-instruction administration of the psychomodeling instrument.)

change in materials. Thus, the function of photosynthesis is in terms of the role of each of the mixed elements.

Patterns of Change Reflected in Group Data. The group data shows that most of the students (62%), including Ben, were unsure prior to instruction as to whether plants make their food (see Figure 19). Few students (14%) believed that plants make their food while 24% of the subjects held to the belief that plants do not make their food. Eighty-one percent of the subjects, including Ben, believed that plants take in their food.

Following instruction those believing that plants make their food increased to forty-eight percent. Most of those who held this belief (60% of those believing plants make food) were unsure prior to instruction. Twenty-three percent of those who were unsure prior to instruction, including Ben, came to believe plants do not make their food.

It is interesting to note that prior to instruction those who believed plants make their food were not aware of the importance of light; they responded that plants make food in light or dark (see Figure 20). Following instruction only one of these students conceptualized the importance of light. Only one student showed evidence of believing that plants make their own food using light, air, and water.

Key Non-Changes

The selection of three conceptual changes identified in Phase I which were thought to merit further study was followed by an analysis which was revealed in the previous sections. The preceding analysis of those changes focused upon the description of classroom occurrences, as well as teacher and student actions, emphasizing those aspects of instruction which were identified as being directly relevant to those changes identified in Phase I. Each case focused upon the instructional activities associated with one of

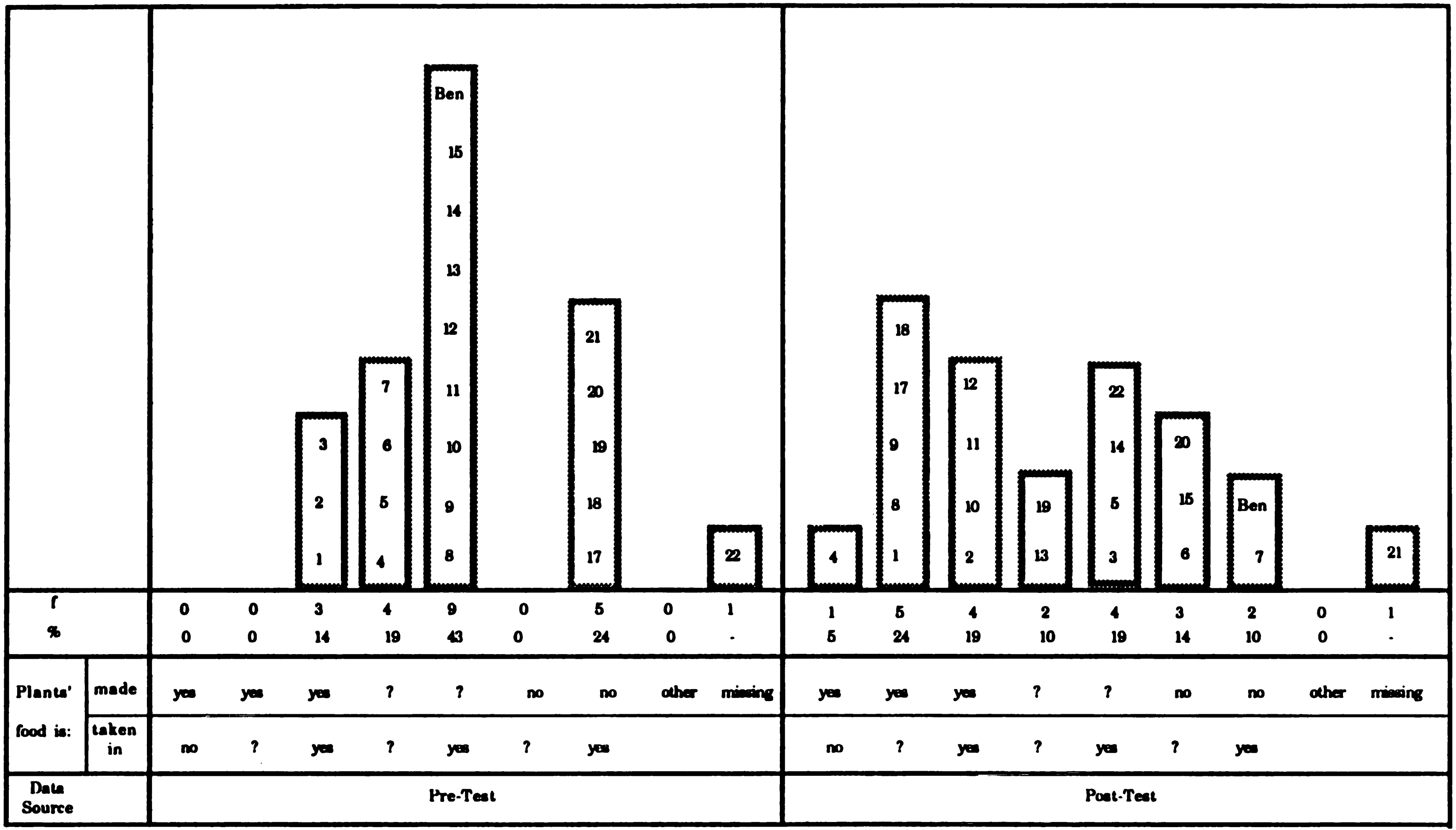


FIGURE 19. ALTERNATIVE VIEWS OF HOW PLANTS GET FOOD. (This shows how classroom students' viewed how plants get food before and after instruction.)

Data Source	Pre-Test							Post-Test						
Alternatives	make using light, air and water	make in light	make in light and dark	make in dark or in ?	do not make food	unsure	missing	make using light, air and water	make in light	make in light and dark	make in dark or in ?	do not make food	unsure	missing
			1	3, 2	8, 7, 6, 5, 4	21, 20, 19, 18, 17, 16, Ben, 14, 13, 12, 11, 10, 9	22	9	4, 1	11, 10	14, 13, 12, 5, 2	18, 17, 16, Ben, 6	22, 21, 20, 19, 7, 3	8
f	0	0	2	1	5	13	1	1	2	2	5	5	6	1
%	0	0	10	5	24	62	-	5	10	24	10	24	29	-

FIGURE 20. ALTERNATIVE VIEWS OF LIGHT AND PLANTS MAKING FOOD

the identified conceptual changes in an effort to expose relevant patterns and regularities.

Ben's Naive Theories. Ben possessed descriptive and explanatory systems for the scientific phenomena which was the focus of the instructional unit before experiencing the formal study of the subject. Prior to instruction Ben viewed food for plants to be various external raw materials including light. Based upon knowledge asserted during Clinical Interview 1 and the responses given on the pretest the following propositional knowledge was part of Ben's framework.

I2: Plants (do not) make food.
KL: Plants (do not) make their own food in (light).
MK: Plants (do) take in their food from (soil).
O1: Food for plants (is) (water, fertilizer, soil, light, minerals, air, vitamins, nutrients).
OK: Food for plants (is) (water).
OL: Food for plants (is) (fertilizer).
OO: Food for plants (is) (light).
OT: Food for plants (is) (air).

There was evidence that Ben believed that fertilizer is food for plants. He indicated that fertilizer is food for plants but then elaborated that "seeds absorb fertilizer from sunlight, soil, manufactured fertilizer, decomposed objects, and water." Thus, he believed plants get this food from the soil, light, water, organic matter, and manufactured fertilizer.

Notable by its absence in interview one was any mention of food coming from or being stored in the seed; he did not bring it up in the interview despite several opportunities. The important insight at this point is that Ben believed plants get something from these materials. In his view the raw materials are a source of "nutrients."

Ben's preconceptions of what constitutes food for plants involved external raw materials. These materials (water, light, etc.) are the sources of something ("fertilizer" or "nutrients") used by the plant to live and grow. These materials are "taken in" or as Ben referred to it "absorbed." His conception of light was that it provides plants with nutrients; it is a source of food. Food for plants is something external, something taken in, and consists of nutrients in the air, soil, light, and water taken in by the plant.

Model of Conceptual Change. The focus of this section is to describe and apply a theoretical model of conceptual change in an effort to provide a framework which can guide further conceptual change analysis. The importance of a theory to guide the inferential process has been argued previously (Lott, 1980a). Experience can not be described independently of theory because what counts as experience is necessarily theory dependent.

The view of conceptual change proposed by Posner, Strike, Hewson, and Gertzog (1982) places an emphasis upon the interaction between the subject's internal processing of information and the encounter with the environment. It considers the environmental context as well as the intentions of the teacher and student to be important factors in the reconciliation of internal conceptual conflicts. It is within this context that they argue that "a new conception is unlikely to displace an old one, unless the old one encounters difficulties, and a new intelligible and initially plausible conception is available that resolves these difficulties" (p. 220).

The view of the teaching-learning process which results from the adoption of this model of conceptual change reflects the epistemological and theoretical principles reviewed in Chapter 2. It suggests four conditions that must be fulfilled if students are to make changes in their conceptual framework:

- there must be dissatisfaction with existing conceptions,
- a new conception must be intelligible,

- a new conception must be initially plausible, and
- a new conception must appear fruitful (i.e., lead to new insights and discoveries).

The model requires more of the teacher than simply the occasioning and structuring of content. Moreover, the student is required to go beyond the apprehension of the information content and its integration into the conceptual framework and must produce a way to deal with the incongruous situation. The model accepts the argument by Magoon (1977) in which the teacher and students are seen as "purposive agents whose thoughts, plans, perceptions, and intentions influence their behavior and moderate the effects of behavior" (p. 652).

The nature of the encounter between Ben's preconception of food for plants and the information content of the learning experiences is the first point of interest in the effort to compare the actual results with what might be expected if the model was applied to the literal program. The literal program indicates that the teacher will occasion discussions aimed at reporting the empirical observations of the students. The patterns thus exposed are used to influence the subjects to justify their current conceptions in the light of the encountered evidence and where necessary reconcile conflicting conceptions.

It is predicted that Ben's involvement in the learning experiences where he reviews his conceptual framework in the light of new evidence will result in several changes or alterations in his conceptual framework. Based upon the model, these changes will be influenced by the interaction of environmental factors such as teacher and student acts within the framework provided by the learning experiences and the internal reconciliation processes of the student. This will have begun with the teacher occasioning a discussion directed at having the students' interpret the evidence gained from their grass experiment. It is this episode in the instructional sequence which will make public the alternative frameworks used by the students in response to what Nussbaum and Novick (1982) refer to as an "exposing event" (p. 4). This event consisted of the response of plants to the experimental set-up for Chapter 5 where it is observed that those plants grown in light continue to live while those in the dark eventually die. A network representation of Ben's knowledge structure concerning plants and food, based upon the application of the model, is given in Figure 21.

The conceptual framework representation shown by Figure 21 provides evidence that several aspects of Ben's preconceptions have been altered. In activity nine of Chapter 5 the teacher through her questioning enables Ben to make "an imaginative leap which enables a new way of thinking about a problem to take place" (Driver and Easley, 1978, p. 80). This leads to Ben's falsification of two frames; one concerning where plants get there food and the other regarding what food is for plants. As a result Ben changes his conceptual framework through the addition of the network involving photosynthesis.

It would be expected that MK (plants do take in their food from the soil) would be rejected in exchange for MA (plants do not take in their food from the soil). This would be the consequence of the encounter with the evidence regarding the growth of seed parts in the germination system. Ben observed that the embryo and cotyledon as well as the whole seed grew while placed on a piece of blotter paper. This experimental environment and his internal mental search for consistency would lead him to the "exchange" of propositional knowledge.

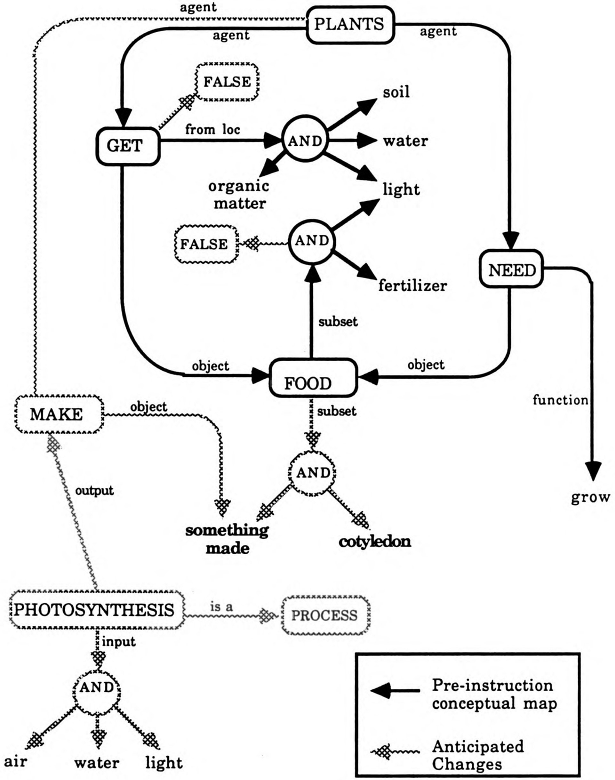


FIGURE 21. BEN'S ANTICIPATED POST-INSTRUCTION CONCEPT MAP.

In addition, OL (food for plants is fertilizer) and OO (food for plants is light) will be rejected in exchange for OI (food for plants is the cotyledon) and OJ (food for plants is something made). The realization that plants do not get their food from the soil would lead Ben to adopt the proposition that the cotyledon is food for the plant. His observations of grass growth under varying conditions would provide a contradiction of frame OL and in conjunction with the classroom discussions in which he has participated he accepts the teachers' explanation.

Moreover, these "conceptual exchanges" (Hewson, 1981) will have resulted from the addition of frame K and L alternatives KA (plants do make their own food) and LA (plants do use light to make food). The inclusion of these frames could be expected as the result of Ben finding that his preconceptions concerning where plants get food and what food is for plants are not "fruitful" (Hewson, 1981); they do not explain the observations he has made of grass growth in the light or dark. His application of the propositional knowledge put forth by the teacher as an explanation in lesson 5.10 could be found by Ben to have internal consistency when the negation of several frames is internalized. This in conjunction with the teachers' "invention" of photosynthesis would provide a fruitful conception; one which can be used to explain the outcome of the grass experiment.

This exposure to other students' interpretive frameworks in conjunction with the teacher's probes concerning the function of light for plants and food for plants would activate certain frames or cognitive structures on the part of Ben. His attempt to reconcile these activated frames with what he is experiencing would bring about a conceptual conflict involving the frames M and O. The teacher's skillful probes using student alternative frameworks along with empirical and theoretical evidence would lead to Ben's restructuring his interpretive framework.

The application of this model to the sequence of events as described in the literal program would be expected to result in Ben's having a conceptual framework as represented in Figure 21. However, it was observed that throughout the period of instruction the students continued to maintain their preconceptions of food for plants. A review of Ben's postconceptions in contrast to his preconceptions reveals that he has experienced a transformation of conceptual framework. Yet that modification of conceptual structure involved what Hewson (1981) has referred to as "conceptual capture" as opposed to a "conceptual exchange." The concepts present in the preconception representation have been retained yet with the addition of several new concepts (e.g., cotyledon, chlorophyll and photosynthesis) the relationships have not been changed.

The preconception of food for plants was not displaced but was reorganized to include a mechanism for the absorption of food, a substance for making the plant green, and a process for the mixing of food sources (cf., Figure 19). As a basis for further analysis, at a level of detail sufficient to discover why the expected changes were not observed, the following sections are intended as a review of Ben's experiences of instruction.

Ben's Conceptual Evolution. During a classroom discussion in lesson 4.4 Ben encountered, as the result of a hypothesis verbalized by a student, the information that the cotyledon provides food for the plant. This was offered by the student in the context of a question in reference to the embryo and whether the cotyledon would grow. The student response was that the cotyledon would not grow, it would "give it (i.e., the embryo) food to grow."

During the next two lessons which followed he encountered the idea that the cotyledon provides food for the embryo. However, this idea would not be in direct conflict with his preconception concerning food for plants. His preconception of food for plants was that it consists of external materials which are "absorbed" by the plant. All of these sources except soil were present during the germination experiment. The observation of the embryo growth when attached to a cotyledon necessitated only that he add to his conceptual framework an object, the cotyledon, through which food could be absorbed. Thus, the observations during the experiment were apparently not problematic and did not challenge the "central concepts" (Posner, et al., 1982) of Ben's conceptual framework.

The teacher consistently referred to seed parts rather than experimental conditions; increasing the potential for confusion (i.e., was a reference being made to the cotyledon alone, or the cotyledon attached to the embryo). This continued the ambiguity of reference as to whether the teacher was alluding to the attached cotyledon as a part of a condition, or the condition consisting of a separate cotyledon.

Throughout the period involving Chapter 5 Ben continued to maintain his preconception of food for plants as water, fertilizer, and light. The central change for Ben during chapter five was his addition of chlorophyll to his conceptual framework as something plants need. This need is in order to have food. It was during this period that Ben developed the belief that plants make chlorophyll and the role of light in this process is to provide extra nutrients. What is taken in is nutrients from the soil and light. There is no indication as to whether chlorophyll is needed to make food or to absorb and transmit food. The consequence is evident (to be green and to live), but the function is not.

Ben's focus on the height during Lesson 5.4 led him to conclude that "plants in the dark grew well because they got nutrients and the food they needed from other sources than the sun." He suggested that plants in the dark get food from water and fertilizer whereas in the light they get their food from light in addition to water and fertilizer.

The discussion during Lesson 5.10, the purpose of which was the interpretation of results, Ben stated that "light gives the plant the food it needs to produce the chlorophyll." Additional statements made during this discussion suggests that while several students had incorporated light into their conception of food for plants, misconceptions continued to persist. While one student stated that "plants turn light into food," another indicated that "plants need light because light feeds them."

It was at this point that the observational evidence suggested that Ben now considers light to be important for plant life. Plants in his view, must have light in addition to other resources in order to live. He also asserted at this point that the cotyledon is food for the plant.

It was apparent following the "invention" of photosynthesis that while he believes plants make chlorophyll, food for plants continued to be something they take in. In particular, he asserted that soil has food in it and the plant takes it out. There was no evidence that he believes plants make their food, however, when the teacher stated that plants have two sources of food, Ben responded by saying that the two sources of food for the plant are the cotyledon and photosynthesis. Moreover, there was evidence that he had internalized a concept of photosynthesis as a mixture of light, air, and water. He stated during the classroom discussion that "the making and putting together light, air, and the water is called photosynthesis."

Thus, he appeared to once again be using a mixture view of photosynthesis rather than the process view.

Conceptual Tenacity. In each case study the central change was an addition to Ben's conceptual framework. His preconceptions persisted despite instruction on scientific theories that contradicted them. Discrepancies between Ben's post-instruction conceptions and the scientific theories taught often represent important failures of instruction. The research suggests that preconceptions actively compete with scientific alternatives as organizing structures for students' experience of instruction and as explanations for their everyday experience.

Throughout the period following the "invention" of photosynthesis Ben continued to maintain his preconception of food for plants to be water, fertilizer, air, and light. Based upon knowledge asserted during the observation of instruction as well as during the clinical interviews and the responses given on the pre- and post-test Figure 22 shows the continuity of several aspects of Ben's propositional knowledge.

This figure shows that as other conceptions were being incorporated into Ben's conceptual framework those which were present initially remained. Some of these coexisted with contradictory conceptions as well as goal conceptions. This provides evidence that students may develop conceptual structures as a result of instruction and other experiences which can be internally consistent and quite elaborate, but which are inconsistent with the scientific explanation of the phenomena they observed.

A review of Ben's postconceptions in contrast to his preconceptions reveals that he has experienced a transformation of cognitive structure whereby new concepts and principles were combined with previous knowledge. His view of food for plants, however, continued throughout this

f PROPOSITION FRAME	LESSONS																
	Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
K Plants (do/do not) make their own food in (condition: light/dark).	2 9 L M															1		O C L
M Plants (do/do not) take in their food from (location).	23 92 K3	L3 O2 N						2 L		K L			K				K2	23 1 K2 8 A O M
O Food for plants (is/is not) raw (materials).	1 A 3 92 K O T	5 L O		L	K2	K L O			O	O		J	M	I		I J P	F I K L M O T	12 A 42 I K2 L J P O2 T2

FIGURE 22. KNOWLEDGE ASSERTED BY BEN CONCERNING FRAMES K, M AND O

period to be formed around raw materials (i.e., water, fertilizer, air, and light) which contain nutrients that plants take in. The concepts present in the preconception representation have been retained yet with the addition of several new concepts; cotyledon, chlorophyll and photosynthesis (see Figure 23).

Ben previously indicated a belief that food for plants is "fertilizer" taken in from several forms of matter. He now conceptualizes food acquisition for plants to include the cotyledon as a source as well. He has assimilated the idea that the cotyledon provides food or is a source of food in terms of the cotyledon being a mechanism for collecting and transmitting food for the young plant.

He also continues to believe that the role of light is to provide plants with the extra nutrients needed to make chlorophyll. The knowledge asserted following the completion of Chapter 6 reflects Ben's new affirmation of photosynthesis as a source of food for the plant. This is further elaborated as he indicates that photosynthesis is the "getting together" of food sources for the plant.

The evidence indicates that he seems to believe that photosynthesis is a mixture of water, air, and light; that it is "stuff," not a process involving change. It is a process in which the food sources for the plant are combined; an <u>action</u> involving the mixing of food sources. His addition of photosynthesis seems to involve a view similar to that which he developed for the cotyledon feeding the plant; a mechanism for transmitting food. He does not view plants as making their food, but rather as engaging in a taking in process and "putting together"; there is no change in materials. Thus, the function of photosynthesis is in terms of the role of each of the mixed elements.

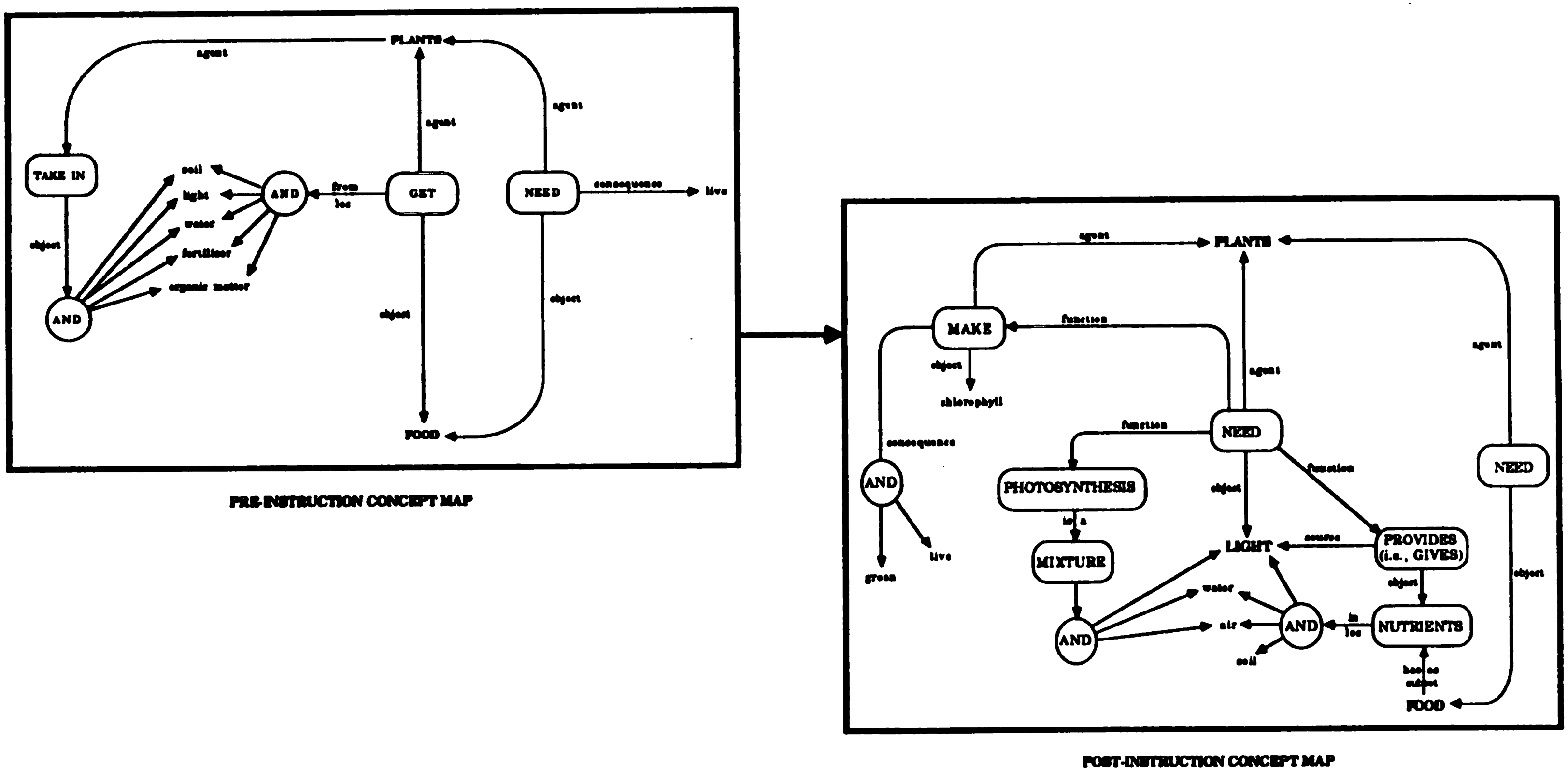


FIGURE 23. BEN'S CONCEPTUAL CHANGE.

The data reviewed in the case studies reveals that for the most part the instruction failed to bring about the intended changes in Bens' conceptions of the source of food for plants. The results also indicate that Ben did not understand an important empirical relationship intended as the major challenge to his preconception that plants get their food from the soil. The instructional strategy of the literal program builds upon the anticipated results that plants left in the dark die while those in the light turn green and grow, despite the fact that the soil is the same in every planter cup. However, the post-instruction data (i.e., the sixth clinical interview, posttest results and propositions asserted during the final lesson) indicated that this result was not apparent to Ben.

The results of this and other studies indicate that traditional instruction does not facilitate an appropriate reconciliation of pre-instructional knowledge with the content of instruction. Alternative conceptual systems are remarkably resistant to change by exposure to traditional instructional methods. Moreover, there appears to be evidence that these alternative conceptual systems are not facilitative of the learning process.

While these results were consistent with those reported by other studies (Champagne, Klopfer and Gunstone, 1982; Nussbaum and Novick, 1982b), it was anticipated that the methodology developed for this study would furnish sufficient data to achieve a greater depth of understanding. This 'thicker description' would provide an account of the ways that instruction seemed to go wrong when it might have been otherwise. It is important to consider carefully the adequacy of the instruction and, in particular, the strategy for occasioning the instruction in making judgements about a theoretical base (i.e., model of conceptual change).

Issues Revealed in Case Studies

The analysis led to the identification of several patterns which yield insights concerning the ways you can go wrong in attempting to bring about conceptual change. It is argued that the "thick description" (cf., Geertz, 1973) provided in the case studies exposed occurrences which took place during instruction that will provide insights into the dynamics of student concept formation. The problems identified which appear to have general implications for cognitive instruction included the findings that instruction was in some ways attacking the wrong preconception, that communication was sometimes hampered by systematic sources of ambiguity, and that some important issues were not adequately framed through the use of appropriate questions.

A more detailed examination of some critical class discussions using the transcript data will provide some interpretative patterns. The following sections describe and document those aspects of instruction which seemed to explain the disappointing learning results in this study.

Students and Experienced Instruction

The students' actions and their responses to phenomena are viewed in this section against the background of the experiences occasioned in the environment of the classroom.

Observations and Encountered Ideas. Changes in student knowledge were influenced by several different kinds of encountered information. Information content was inherent in observations of phenomena and abstract ideas expressed by the teacher or other students.

Observations of phenomena played important roles in the process of knowledge change. They provided the basis for the addition of descriptive propositions (or empirical generalizations). The shrinking of the cotyledon seems to have been very influential. During his involvement in the activities of Chapter 4 Ben observed the growth of the embryo only when attached to the cotyledon. During Lesson 4.4 he also observed the cotyledon shrink in size as the attached embryo grew. This proposition was reaffirmed several times during Lesson 4.7 in which students indicated their conjecture concerning seed part functions.

> John: I just had a brainstorm that
> maybe/
> /I'm beginning to think that the cotyledon
> does give the embryo it's food. Cause
> I'm not/
> /I'm not/
> /cotyledon/
> /it seems like the cotyledon must have shrunk a
> little bit. What I think maybe happened is the
> cotyledon gives the embryo/
> /it gives/
> /more than the source that I first thought of
> food. It gives it and/
> /it/
> /it starts shrivelling up cause it's giving
> the embryo food.

John picks up on the teacher's point and it is quite important to him, "a brainstorm." The observation of the cotyledon actually shrinking at the same time that the embryo was growing may have been suggestive, in Ben's view, of something going from the cotyledon into the embryo. He formulated the belief that what was being transferred was water, a source of food. The most plausible inference in Ben's view, as the result of internalizing an interpretation of the observations and experiences during chapter four, was that the cotyledon collects and transmits food to the embryo.

Other observations provided the basis for the change in contradictory propositions already a part of the students knowledge base. Prior to instruction Ben suggested that plants continue to live in the light or dark because they get food from soil. Ben's intermediate knowledge state showed evidence of a change of his view of the consequence of the absence of light. It was at that point, during the observations of grass in the light and dark, he asserted that light was necessary for plants to live. In conjunction with this he asserted that plants continue to live only in the light because plants need light to make chlorophyll.

Observations also helped to drive the process of making other changes by providing something that needed to be explained. The importance of light, the idea of plants being green and its relationship to light, developed from empirical evidence. The conditions which framed the encounter with the empirical evidence entailed student observation of plants switched from the dark to the light. During a discussion aimed at interpreting their observations the students were asked to describe these plants. The responses lead to the exposure of a relationship between light and plant color. The inclusion of chlorophyll in Ben's conceptual framework was the result of an assertion by a student during task five of Lesson 5.5 (see Table 3) which gave him an explanation in the form of a mechanism which resolved his sense making process concerning the observed relationship.

Ben's conceptual change as a result of the empirical observations seems to involve what Hewson (1981) refers to as a "conceptual capture." This involves the process by which a prior conception is reconciled with an encountered conception. Moreover, this is an example of how the statements of others, in an appropriate context, can influence a change.

Abstract ideas presented by the teacher or other students also played an important role in the process of knowledge change. They provided propositional links which helped students construct explanations relating empirical generalizations to existing knowledge structures.

TABLE 3.

Lesson 5.5 Discussion Concerning Chlorophyll

	Information Content	Source
25	Plants switched from the dark to the light turned green because of the sun.	Student
26	Light has changed the color.	Teacher
27	The sun gives it the extra food and nutrients it needs to get back the normal color of any other plant.	Ben
28	The sun or the light has changed it back to green.	Ben
29	The plant can not produce chlorophyll without the sun.	Student
30	The chlorophyll is the green.	Student
31	The light from the sun has changed the color to green.	Teacher

The evidence (Lott, 1983c) provides a focus toward lesson five during which a student introduced information content concerning chlorophyll after which Ben refers to the color of the plant.

176	T:	Louis, why do you think Heather's plant is green now and it was yellow before? She moved it from the dark to the light.
177	Louis:	Uha, if it was in the dark then it would, uha ...
178	T:	Bobby?
179	Bobby:	Because of the sun.
180	T:	Alright you think some light changed the color, okay, Ben?
181	Ben:	Well the sun gives it the extra nutrients and food it needs to get back the normal color of any other plant.

The knowledge asserted during instruction (Lott, 1983c) as well as in the fourth clinical interview reflects Ben's affirmation of chlorophyll as what makes plants green. This is further elaborated as he indicates the plants need for chlorophyll and an awareness of the importance of light for a plants color and its living processes. The knowledge of chlorophyll helped explain green in light and yellow in dark. It is shown in the interview that he views plants having food as contingent upon color which is dependent upon the presence of chlorophyll.

Ben: They need the light to make the/
/like on trees. They have light to make chlorophyll for their leaves. On plants their leaves are their stems and trees don't have stems so when the chlorophyll isn't made the stems will turn a very light yellow, lose their coat and then just die.

I: You mentioned chlorophyll, could you tell me a little more about that?

Ben: Well, chlorophyll is a substance/
/see the plant has all the things in it to make except for one so in the one missing thing is the ultra-violet rays from the sun and that gives it the last ingredient it needs to make the chlorophyll. Now when it doesn't get those ultra-violet rays from the sun then it can not make the chlorophyll so it dies.

I: Could you tell me a little bit more about what the chlorophyll does for the plants?

Ben: Well, the chlorophyll is the color of the plant and it keeps/
/lets say on trees, every time the leaves lose their chlorophyll which is when the supply gets shut off because of winter, they fall off because they have no life left in them. The same thing happens with plants when there is no chlorophyll to give them to keep living they just die.

The importance of light developed during task 4 of Lesson 5.10 where an abstract idea (i.e., photosynthesis) was presented by the teacher as a process for putting together the food sources of the plant. What took place was a teacher presented idea which the student's perceived as a food giving process to explain the empirical observations they encountered.

Propositional Links. The process of knowledge change involved active construction by the student of propositional links not explicitly encountered in instruction (see xxxxxxxx in Figure 14). This involved active sense making whereby the student used "pieces" available to build connections and construct links, which were used for "making sense" of classroom observations.

The incident previously discussed is a case in point in which observations influenced changes by providing something that needed to be explained. The empirical evidence (i.e., light and color) with the information content input (i.e., chlorophyll and its relation to color and light) enabled Ben to construct (i.e., integrate information content) a new conceptual framework which was different but consistent with his previous conception.

It was in Clinical Interview 3 that it becomes evident that Ben realizes plants need chlorophyll to be green. He also believes that the function of light is to provide the food nutrients to make the chlorophyll. This may have been the result of his encounter with the empirical evidence that plants need light to be green in conjunction with information content provided by other students in Lesson 5.5 and task five. This interaction of empirical evidence and information content was observed in an earlier example which referenced the discussion which took place as part of task 5 of Lesson 5.5. The interaction of interest took place at the point where the class is discussing those plants taken from the dark and placed in the light.

Preconceptions and Experienced Content. Although it has been hypothesized that preconceptions (e.g., naive conceptions) influence the interpretation of events and therefore can affect learning (Ausubel, 1960, 1963), the results of this study provide clear instances as well as documentation to support this conjecture. The preconceptions held by students continued to influence, as might be expected, how they interpreted the natural phenomena which were observed as well as the information content which they encountered. These preconceptions, therefore, had an effect upon the learning process and the resultant outcomes.

There was evidence of the influence of preconceptions upon student interpretations. Alternative (i.e., naive) conceptual systems do not facilitate the learning process. These preconceptions may limit the level of "sense making" achieved by the student.

There were several data points reported (Lott, 1983b) which provide evidence of Ben's attempt to make sense. It is argued that for conceptual change to occur, the learner must be trying to make sense of the information content encountered. Making sense seems to involve the student trying to relate new information to some prior knowledge in a way that is, in the learner's judgement, internally consistent (cf., Hewson, 1981). In addition, this seems to be related to Ausubel's (1968, p. 38-39) "set to learn meaningfully."

There was evidence that during Lessons 4.4 through 4.7 he encountered the idea that the cotyledon provides food for the embryo. However, this idea would not be in conflict with his preconception concerning food for plants. His preconception of food for plants is that it consists of external materials which are "absorbed," by the plant. The following transcript excerpt from clinical interview one provides an insight into this conception.

Ben: The seeds need fertilizer for them to grow.
I: Could you tell me a little more about how they get this fertilizer?
Ben: They absorb it from the sun rays and from the soil and other things.
I: Could you give me an idea, you say other things, what these other things might be?
Ben: Well, they would be manufactured fertilizer, decomposed objects, such as dead animals or something, and water.

All of these sources except soil are present during the germination experiment. The observation of the embryo growth when attached to a cotyledon necessitates only that he add to his conceptual framework an object, the cotyledon, through which food is absorbed.

Moreover, his interpretation of plant growth in the light and dark was influenced by his preconceptions. The following excerpt from clinical interview three provides a view of his interpretation of the grass experiment in terms of his explanation of the importance of light to the color of the plant.

Ben: Well, it (the experiment) shows that sunlight gives plants the extra nutrients and food that it needs to make chlorophyll to make it stay green.
I: Can you tell me more about, you mentioned chlorophyll, staying green?
Ben: Well, the plant, it makes chlorophyll from the sunlight that it takes in when there's light hitting it. When there's no light hitting it, it can't produce the chlorophyll that it needs to keep the green.

Light remains a source of nutrients, but more specifically it enables the plant to make the chlorophyll which it needs to be green. The explanation of plants being green is the production of chlorophyll, which does not seem to offer a conflict. Therefore, there is no "change" in conceptual structure. In response to the request for a prediction during Clinical Interview 3 concerning what would happen to the grass plants which were started in the dark and remained in the dark the following was offered.

Ben: Because, they're going to turn yellow because, I told you before, they can't produce the chlorophyll that the sunlight gives the extra nutrients to make. So, also they're going to grow normally because they get all the nutrients to grow from the water and the soil.

This explanation in terms of nutrients, and in one case during Lesson 5.10 and task 3 making reference to food, is consistent with his preconceptions.

It is near the end of chapter six that Ben asserts the importance of photosynthesis. However, there is evidence (Lott, 1983c) which directs attention to Ben's idiosyncratic conception of the nature of photosynthesis. This conception is also affirmed by many of the students during a discussion in task 3 of Lesson 6.9 where they use a mixture view of photosynthesis rather than a process view. During this discussion there is the appearance of the mixture view with some clarification of consequences.

36 Dan: Well, I said it depends and/
/reason I said that is cause I think if it's very close to the front of the cave and/
/it'll still survive because of the light coming in and if it is pretty far near the back, then it won't live because it doesn't have all the photosynthesis.

41 Sam: It doesn't have the whole photosynthesis, though. It might happen but we don't know if it does or not.

56 T: ... Yeah, I think we were saying a minute ago that plants needed photosynthesis. And what is that? What is photosynthesis?

62 T: Okay, let's hear from somebody else now. Janet?
63 Janet: Well, most plants need photosynthesis.

65 Janet: Well even if they needed photosynthesis, two out of three isn't bad. Okay, because I tried with, I didn't give it any air it just had water and it died.

The above discussion provides evidence that the students place some importance upon the presence of light for continued plant growth. A student later elaborates that the plants in the cave would not have "all the photosynthesis." This is offered as an explanation by another student. This "part" concept continues to be used by the students in their explanations. The students seem to believe that the parts of photosynthesis are themselves food sources for the plant and it is merely a mixing process, not a process of change and food production.

The preconceptions of student's continued to affect how they interpreted the natural phenomena which were observed as well as the explanations offered the teacher. In many cases student interpretations in terms of their preconceptions lead to only the "capture" of knowledge content.

Persistence of Preconceptions. While there is direct evidence that these naive conceptions have a tendency to persist following instruction (Champagne, Klopfer, and Gunstone, 1982; Driver and Erickson, 1983), the results of this study provide clear instances as well as documentation to show how they can persist. Alternative conceptual systems are remarkably resistant to change. Despite additional pieces of information being added to an individual's conceptual network there is frequently no change.

An examination of the classroom interaction gives some indication of why the preconceptions persisted. Although additional pieces of information were added to the student's conceptual network as the result of classroom experiences, their preconceptions were frequently not challenged.

It was reported in the first study (Lott, 1983a) that Ben's preconceptions continued to affect how he interpreted the natural phenomena which he observed. The teacher's belief system led her to view the situation in terms of "if the cotyledon is seen shrinking then, in light of the argument developed in class discussion, it is consistent that the cotyledon is food for the young plant." However, Ben's preconceptions persist since the evidence was consistent with his conception of food for plants. This resulted in his belief that what was being transferred was water, a source of food. As a result he concluded that the cotyledon must be a source of extra water which in his view is a food source along with soil, organic matter, and light as he had asserted in the first clinical interview. Specifically, this change may have been influenced by Ben's experiences in Lessons 4.2 through 4.7 in which he observed the embryo grow only when attached to a cotyledon or whole bean. The embryo alone and the cotyledon alone did not grow.

An analysis (Lott, 1983c) exposed that Ben's preconceptions also continued to affect how he interpreted the natural phenomena. The teachers belief system led her to view the situation such that in light of the argument developed in class discussion, it is consistent that plants make their food using nutrients from light, air, and water. The end result being a new substance not found in any of these raw materials. However, Ben's preconceptions are not brought into question and they persist. The evidence was not inconsistent with his conceptions of food for plants (i.e., his "consequences" were correct). This seems to be related to the view of Nussbaum and Sharoni-Dagan (1983) that unless distorted conceptions are challenged they will be used in future encounters and will shape the conceptions later formulated.

A case in point is the point in instruction at which Ben gives evidence of having made the relationship between the color of plants and the presence of light. Another student asserts that chlorophyll makes the plant green and that the plant can't produce it unless there is light. The following provides a glimpse of the interchange in which this occurred.

Ben: Well the sun gives it the extra nutrients and food it needs to get back the normal color of any other plant.

T: Okay, so you're saying the sun or the light has changed it back to green.

Ben: Yeah.

T: Okay, John?

John: Well, the plant cannot produce chlorophyll without the use of the sun. Chlorophyll is what makes the plant green.

T: That's the green, okay, so it's the light from the sun that can change the green, okay...

Directly following this lesson Ben gave evidence of chlorophyll being the mechanism by which plants remain green in light. In this case Ben seems to have performed integrative activities in the process of making sense of his encounters. Integrative activities are those which fit new ideas and material together with what the student already knows.

Teacher's Moves and Their Effects

The teachers actions are viewed in this section against the background of the program and the intended learning outcomes. Actions on the part of the teacher provided a framework within which observational encounters were experienced, provided direction which guided the behaviors of students, and lead to unresolved ambiguities.

Observational Encounters. The focus in this section is upon the identification of "events" which in retrospect could have performed as "exposing events." These are events (cf., Nussbaum and Novick, 1982) in the instructional sequence which lead to an episode which will make public the alternative frameworks used by the students. Properly occasioned events "encourage students to articulate them" (i.e., alternative conceptions) (Nussbaum and Novick, 1982, p. 188). Nussbaum and Novick (1982) suggest that these "events" go beyond the "learning cycle" (Karplus, 1977) and "make an effort to analyze the assumptions" (p. 188) which are the basis of a student's misconceptions. Just as the "learning cycle" went beyond the ESS open activity, with the structured exploration where preconceptions were exposed, the "exposing event" goes another step and encourages the teacher to require the student to analyze the assumptions behind what s/he has stated.

This section will identify those events which might have served this function, but which actually lead to the retention of misconceptions. Insights into the role of anomalies in experimental results, and the discussions which followed, provide a framework for understanding why these events did not provide a foundation for conceptual change.

Selected tasks, whether intended or not as part of the program design, could be viewed as "exposing events." However, these tasks did not provide support for later discrepant events and therefore did not result in laying the ground work for conceptual change. In two cases the teacher merely provided the environment for the students' to verbalize their concepts, she did not get them to juxtapose their concepts or did she challenge them (i.e., "what is your evidence," "could you explain that further").

The intent of the activities of Chapter 4 was that the empirical evidence of the shrinkage of the cotyledon will support the development of several theoretical propositions during a discussion in Lesson 4.5 aimed at interpreting the observations made by students during the investigation. However, the teacher did not conduct the discussions such that they would "expose" the conceptual framework being used by the student.

As previously described, the observation of the cotyledon actually shrinking at the same time that the embryo was growing may have been suggestive, in Ben's view, of something going from the cotyledon into the embryo. He formulated the belief that what was being transferred was water, a source of food. The most plausible inference in Ben's view, as the result of internalizing an interpretation of the observations and experiences during Chapter 4, was that the cotyledon collects and transmits food to the embryo.

As reported earlier the importance of light, the idea of plants being green and its relationship to light, developed from empirical evidence. During a discussion aimed at interpreting their observations the students were asked to describe these plants. The responses lead to the exposure, as the result of an assertion by a student during instruction, of a relationship between light and plant color. This relationship involved the plant producing chlorophyll in order to remain green, and the need for light in order for this process to proceed.

The function of the chlorophyll as well as the mechanism by which the function is carried out was not pursued by the teacher. In this case the empirical evidence appears to have influenced the "consequences" of plants having chlorophyll. It is conjectured that the empirical evidence can be very influential in the process to change conceptions, even under the circumstance of poorly developed discussions.

The following discussion, which immediately followed the "invention" of photosynthesis in task 4 of Lesson 5.10, was to focus upon assessing student understanding of food for plants.

1 T: If I were to say to you, the plant/
/a plant has two sources of food. Name

those two sources. How many of you would have an idea about that? Gloria?

2 Gloria: Uhm, water and light?

6 Anna: I don't know if this is right but could it be like light and cotyledon?

7 T: Okay, you're right Anna. One of them/
/when we say/
/one of the two sources of food for a plant/
/one of them we know but we forgot for a moment, Ben, didn't we, is the cotyledon. How many of you agree with that? ... How many of you agree that one source of food for the plant is the cotyledon? Okay, now Anna said the second source was light. Can we work on that a little bit, Anna? And what do we call that process? Okay, photosynthesis. It's mixing and putting together the light/
/the light, the air, and the water, and that is called what, Ben?

8 Ben: Photosynthesis

9 T: Okay, photosynthesis is the second source of food, okay?

This transcript provides further evidence of the development of the idea that photosynthesis is the mixing of what student preconceptions indicate are sources of food for plants.

For conceptual change to occur, the learner must have an opportunity to become involved in verifying activities through the application of his conceptual framework to the explanation of observed phenomena. Verifying is concerned with determining the adequacy of the cognitive structure which is being developed. It has the potential for encouraging a more valid conception. It places the student in the position of determining if alternative conceptions can be reconciled. If this is not found to be possible then conceptual exchange can take place (Hewson, 1981).

There are several points of evidence in relation to this issue of a lack of concept application. An examination of the above transcript data from task 5 of Lesson 5.10 shows that the teacher did not request any elaboration on the part of students of "What is photosynthesis." She leads the discussion and focuses on the "source" of food, but not what it is.

> Ben: It is water, air and light all going in and getting together, cause photo means light and synthesis means combining air and water, so when you do that all three of those are food sources for plants. When it is in the dark it can't have photosynthesis because it only has air and water.
> I: Why is photosynthesis important to plants?
> Ben: They need the light to make the/
> /like on trees. They have light to make chlorophyll for their leaves. On plants their leaves are their stems and trees don't have stems so when the chlorophyll isn't made the stems will turn a very light yellow, lose their coat and then just die.

As he stated during the discussion, "the light, air and the water is called photosynthesis."

A comparison of the instructional overview for Lesson 5.10 and the literal program shows that the teacher did not involve the students in an application of the photosynthesis concept. In addition, she did not have the students complete the brainteaser on p. 9 of the student manual.

This leads to another issue, the guidance provided by the teacher during classroom discussions had a profound effect upon what the students brought away from their experiences.

<u>Teacher Directedness and Task Interpretation</u>. The pedagogical acts performed by the teacher influenced the student learning outcomes. The teacher's interpretation of the guide and her presentations influenced the student's observations and interpretations. In this sense they played a "directing" role and at times left preconceptions unchallenged.

An important aspect of analysis is the determination of what task the student engages. This involves the exposition of the student's interpretation of the assigned task. The instructional strategy for this unit involves a series of questions which frame discussions of the experiments and observations. Questions actually presented by the teacher may not direct students toward the distinctions which are necessary for the observational interpretation of the question.

The analysis (Lott, 1983b) indicated that the lesson for Chapter 3 was built around two questions. The first question which guided instruction was "What is inside bean seeds?" The question as asked by the teacher was not phrased to direct students toward (or away from) the observational interpretation of the question.

The second question which gave direction to instruction was "what do the embryo and cotyledon do for the plant?" This question appeared to have been both understood and engaged by most of the class. During the discussion about half the class contributed ideas, all of which appeared appropriate to the question.

In order for the process of conceptual change to proceed the teacher must bring to the attention of students important distinctions which bear upon the problem to be solved. The need is for the teacher to occasion appropriate patterning activities (cf., Johnson, Rhodes and Rumery, 1975). These are activities which enable the students to impose some kind of order on the elements of study.

In Chapter 3 this took the form of the teacher's presentation of the chart showing the seed parts had in the students' observations. Several students apparently did not initially notice the embryo. However, once these students had reason to believe that there was another part, they returned to their seeds to look further and found the embryo.

The discussion of seed parts and their function during Lesson 4.7 evolved around what constitutes "food" for plants.

36 Dan: Well, if you ask me I'd say that/
/well, I think it gives it food. It gives it
shelter because, you see, when (inaudible) all
those whole seeds are way up there you know.
37 T: Yes.

45 T: Any evidence or anything to support the statement that
it is the food, that the cotyledon is the food.
46 Davy: Yeah, I think so (inaudible) that the cotyledon
gets/
/the embryo gets food and (inaudible) shelter.

Once the idea had been brought forth the teacher then seized the opportunity to develop the concept that the cotyledon is food and that this can be used to explain the phenomena they have observed. What followed was student responses to the teacher request for evidence. At the point indicated by the following transcript excerpt the teacher seeks an assessment of student understanding.

T: Okay, Dan. Do you want to say anything more about that?
How many of you feel as though the
cotyledon/
/we maybe should have checked. How many of you feel as
though the cotyledon is the food? How many of you agree
with Dan about that? How many of you feel that the
cotyledon feeds the embryo. Wait a minute Reed, I'm
asking a question and I want to see hands. How many of
you feel as though, or think .... that the cotyledon
.... provides the food .. provides the food .. for the
embryo or the plant?

In the above instance the teacher has stated two questions. There is some doubt as to whether the teacher realized that there were two distinct questions as opposed to being a single question phrased two different ways. The discussion continued during which the argument was further developed through reference to the shrinking cotyledon. It was then affirmed that young plants must get their food from the cotyledon, soil, or water.

The teacher seems to believe, based upon her structuring of the discussion, that the exposure of student ideas will provide information content which will lead the students to realize that their view of the world is limited in its ability to provide an explanation of the experimental phenomena. In her view this will result in the inclusion of the proposition "Food for plants is the cotyledon." However, evidence from the transcript for task 3 of Lesson 4.7 indicates that only a few students comprehended this.

> Samuel: I think you would, because the cotyledon would serve as food, because when we looked at ours for the ninth day I think .. the cotyledon with the embryo/
> /the cotyledon was hollowing out, and the embryo was getting a little bigger but it fell off. It was getting fatter and longer but it fell off.

It was at this point that John made reference to the cotyledon being food for the plant when, as quoted earlier, he stated that the cotyledon "starts shriveling up cause it's giving the embryo food." The discussion goes on with:

> Heather: I just want to say that
> I/
> /the/
> /probably the cotyledon is maybe the embryo's food.
> T: A hum.
> Heather: and the embryo probably eats the cotyledon.

The discussions were again sequential in nature and did not require the students to justify or give evidence. Neither did these discussions provide any challenge to the students conceptualizations. It was as though if they heard all the ideas they could put it together themselves.

There are several points during the instructional sequence for Chapter five where the evidence, which was used earlier to expose the persistence of preconceptions, indicates that this direction may not have been offered or was misguided. During Lesson 5.10 the proposition that plants need light to make chlorophyll was once again asserted. However, when an anomaly concerning the plant in the dark not getting enough food and the result being its death arises the teacher did not pursue it. There is no indication that a logically based conclusion has been made that a plant's living is the consequence of making chlorophyll.

Ben: Well, I think that it gives
it's/
/the/
/ah/
/the/
/ah/
/the rays of the light gives/
/gives the plant the extra/
/the food it needs to produce the chlorophyll. And also, I want to say in my extra experiment I/
/I was/
/it would have been planted/
/my plant had been planted in the dark but it had been kept very warm. Well, it stayed green? ..
T: Okay.
Ben: I don't really understand it?

The questioning pattern involved the teacher posing a question and then seeking student responses in sequence. This provided an atmosphere for ambiguity, the non-challenge of student interpretations and the persistence of preconceptions. Few beliefs or hypotheses offered by students were challenged for justification or juxtaposition with the conceptions of others. These tended to result in the development on the part of students of inappropriate or incomplete conceptions.

This is reflected at several points in the transcribed discussions. In task 5 of Lesson 5.5 during a discussion referenced regarding the persistence of preconceptions, the teacher was observed requesting an explanation for the color change which has been observed. She accepts a sequence of responses; responses which in this case are acceptable. However, she does not probe the response for further clarification or concept development.

Neither does she probe for evidence of the assertions made. During the discussion in task 3 of Lesson 5.10, which was referred to above, Ben raises an anomaly which the teacher did not pursue (may have provided some enlightenment on light (ultra-violet) and plants in dark). However, Vickie picked-up on this but the teacher once again does not use this to provide insights into the alternative frameworks being used.

13 Vickie: Well, you know the sun in
the/
/in the summer most of the time/
/and the/
/the winter you feel like you don't want to be active and run around all the time. People just don't want to sit down, but in the summer you like to lay there/
/go to sleep, and lay down in the shade.
14 T: Ah, hu, okay.
15 Vickie: So that/
/so I think it's more of the food.

16 T: Okay, we're talking about the light now. Aren't we?
17 Vickie: The heat.

The teacher in essence accepts the student response and asks for other responses but does not probe for insights into student conceptions.

The results of an analysis of the lessons which influenced Ben's view of plants and food (Lott, 1983c) indicated that a task during the final lesson of Chapter 5 which is intended to provide direction for student concept formation was omitted. The second task of the activity "invent photosynthesis" as suggested in the teacher's guide was not included in the discussion following the "invention" of photosynthesis. Thus, students were not requested to apply the photosynthesis concept to the experiments they had observed. As is pointed out in the teachers guide this discussion would allow students to <u>use</u> the concept of photosynthesis to explain phenomena they had observed. This would provide an opportunity for students to verify their conceptual framework; to determine its adequacy. The consequence of this task deletion may have been to leave Ben's preconceptions unchallenged preventing any attempt to replace them with more fruitful conceptions.

The evidence (Lott, 1983c) provided a focus toward Lesson 5.10, in particular tasks four and five, where photosynthesis was "invented" and applied in a discussion concerned with plants and food.

The degree of generality of the subject matter is concerned with categories (cf., Johnson, Rhodes and Rumery, 1975). However, the cognitive processes being called for by the teacher are only at the level of recall. This is exemplified in the following excerpt from Lesson 5.10 and Task 4 where it is observed that an explanation was not requested; the teacher did not probe "what is the food?" She is seeking only informed belief, not justified belief.

3 T: ... When sunlight reaches the plant the plant takes in the sun's energy, okay. Uh, the plant uses that energy with the water and the air, okay. The plant uses, Gloria, the light, the sun's energy along, Louis, with the water and the air to produce food for the plant. Samuel, we have a word for that, that process and it's called ...

4 S: Photosynthesis.

7 T: How many of you know or have an idea of what maybe photo means? Gloria?

8 Gloria: Picture.

9 T: Okay, sometimes we think of photograph don't we. Photo meaning a picture. One of the things, I'm waiting ... One of the things that's important when we take a picture, when we hear that word photo, is light. Okay, that's what it means, light. Synthesis means putting (air and water written on board) together. Now what could that be meaning? What could we be implying here when we say photosynthesis? What would be the meaning here?

The teacher continued seeking a response to the question "What do you think that means, light putting together?" She asks for an indication of who has an idea about that. She calls upon several students but none respond and then called on Samuel.

> 10 Samuel: Well photosynthesis means like putting the air, water, and light together to make it's food.
>
> 11 T: Okay, that is very well said. That's the way I like to think it/
> /think about it.

The knowledge asserted in the sixth clinical interview reflects Ben's new affirmation of photosynthesis as a source of food for the plant. This is further elaborated as he indicates that photosynthesis is the "getting together" of food sources for the plant. It is a process in which the food sources for the plant are combined. However, there is also evidence that he seems to believe that photosynthesis is a mixture of water, air, and light; that it is "stuff," not a process. It appears that he continues to believe food for plants is something they take in. What is taken in is nutrients from the soil and light.

A possible ambiguity is introduced in Lesson 5.10 and Task 5 during a discussion which was referred to earlier in reference to observational encounters and their influence upon conceptual change. This potential ambiguity occurred when the teacher makes reference to Anna's indication that "the second source was light," referring to food for plants. She follows this up with the question "what do we call this process?" She has not challenged the student statement and has gone on to refer to the "mixing and putting together" of what data shows students believe to be sources of food for the plant.

Ambiguity. The teacher and student's were using different interpretive frames during their discussions. On several occasions the teacher did not clarify her statements, nor did she request student clarification. This lead to the development of inappropriate conceptions.

Student and teacher interaction was found to be influenced by communication difficulties brought about by the use of different interpretive frames by the teacher and student or by the use of a limiting questioning pattern. This issue was reflected in several points in the transcribed discussions of each case study. The questioning pattern consisted of the teacher posing a question and then seeking student responses in sequence. This provided an atmosphere for ambiguity and the development on the part of students of inappropriate conceptions. Few beliefs or hypotheses offered by students were challenged for justification or juxtaposition with the conceptions of others.

The teacher would generally request an explanation for the natural phenomena observed. She would accept a sequence of responses, however, she would not probe the responses for further clarification or concept development. Neither did she probe for evidence of the assertions made.

In the task culminating the germination system experiment, as reported earlier in the exposure of teacher directedness in relation to the discussion of seed parts and their function, an ambiguity is introduced into the discussion; the ambiguity was concerned with the function of the cotyledon. It was during this period that the teacher used a view of the world which was in conflict with that of the students. This view had to do with what constitutes "food" for plants.

Another ambiguity which was introduced was in reference to which cotyledon shrank, those alone or those attached. The teacher consistently refers to seed parts rather than experimental conditions. The following transcript excerpt from task 6 of Lesson 4.4 provides a view of a discussion in which this occurred.

13 T: Alright, what's seed part did not grow, what would you say, what seed part did not grow. Walt?
14 Walt: Our cotyledon.
15 T: Your cotyledon hasn't grown. Okay, any other. I'm going to be calling on one person at a time. Anything else, any other. Kim?
16 Kim: Cotyledon.
17 T: Your cotyledon has not grown? John.

21 T: Okay, may vary. Alright, do you think though, what happened with your embryo? Report on your embryo. What happened with your embryo?

24 S: Well it started last day, it didn't grow.
25 T: It hasn't grown since the last time? Okay, Anna?

29 T: Okay, the cotyledon, most of you said the cotyledon has not grown. Do you think it's going to grow, say within the next week? Raise your hand, Dan?

30 Dan: No, because it, to me it seems like it shouldn't grow because the embryo seems like to me (in audible)

During this exchange one is left wondering if the students were referring to the cotyledon alone, the cotyledon attached to the embryo, or the embryo alone. This is not specifically indicated by student or teacher in the discussion. This could lead to misinterpretations and the assertion of an invalid proposition. For example, the statement "Our cotyledon" in response to the question "what seed part did not grow" can be taken to mean that the attached cotyledon did not grow or to mean that the separate cotyledon did not grow.

While the teacher did attempt to bring out the shrinkage of the attached cotyledon, with some success, she did not detect the ambiguity.

T: The group yesterday/
/group C noticed that the cotyledon,
um, this is grown/
/the embryo part, the plant part has grown
significantly, hasn't it. They noticed that their
cotyledon was beginning to look a little withered
and it fact like it was kind of dented in. Like,
it was beginning to shrivel up or become smaller.
They noticed the cotyledon had not grown at all
itself, that it was the embryo. And, um, they were
beginning to think yesterday that probably the
cotyledon was serving as food. Reed?
Reed: A, you see what happened/
/the/
/you see/
/like/
/the other things, the embryo and the cotyledon
started growing a lot, but just the cotyledon,
it's kind of/
/went/
/went down/
/it stayed/
/the others started growing, but the ... cotyledon
itself just stayed.
T: Okay, John?

The ambiguity found above was not resolved nor was there an effort to establish what the shrinkage meant. The teacher referred to the attached cotyledon whereas Reed was referring to the separate cotyledon. Reeds hesitancy is an indication of his uncertainty. With his statement the "cotyledon itself just stayed" he seems to have missed the point. This confusion can lead to several meanings. For example, "the cotyledon shrank" can be taken to mean that the attached cotyledon shrank as the embryo grew (a crucial observation for the goal proposition) or to mean that the separate cotyledon shrank (an unimportant piece of information).

In the analysis of the lesson intended to pursue an interpretation of the bean experiment (Lott, 1983c) it was found that the questioning pattern provided an atmosphere for ambiguity and the development on the part of students of inappropriate conceptions. Evidence for this as well as a lack of attention at resolving differences in student conceptions is found in task 5 of Lesson 6.7 where the teacher did not challenge the students to justify their claims (see Table 4).

TABLE 4.

Task 5 of Lesson 6.7 Discussion

	Information Content	Source	Comments
1	Plants in the dark will eventually die, because they have no light.	Student	
2	Whether plants get food from soil depends upon the type of soil.	Ben	
3	Plants get food from the soil.	Ben	
4	Soil has food in it and the plant takes it out.	Ben	
5	Plants don't get food from the soil.	Student	
6	Plants do not need soil.	Student	
7	Plants get minerals from the soil.	Student	
8	Plants have two sources of food.	Teacher	
9	The two sources of food for the plant are the cotyledon and photosynthesis.	Ben	Ben picks up on the teachers interpretation ("sources of food") and refers to an object and a process.
10	Soil provides for deficiencies by providing minerals and vitamins plants need to grow.	Teacher	Ben agrees with this statement.

Although the teacher made reference to plants making food her development of the concept of photosynthesis with the "mixing" and "getting together" idea may have left student preconceptions unchallenged.

Ambiguity was evident in student responses concerning what they thought photosynthesis is. This ambiguity is found in the possible alternative meanings.

1) photosynthesis collects and transmits food to the plant.
2) photosynthesis is a mixture of three substances (light, water, and air) each of which maintains its distinct function.
3) photosynthesis uses air, water, and light to produce a new substance which is food for the plant.

The first alternative conception has the appearance of the cotyledon concept used by Ben, until after Lesson 5.10, and other students. The transcript from Lesson 5.10 and Task 4 used previously to develop the issue of teacher directedness provides a view of the teachers conduct of the "invention" of the concept of photosynthesis.

The teacher's initial statement made use of the idea that plants produce food, however, after she gave the definition reference was consistently made to "putting together" light, air, and water. After the initial amplification of photosynthesis no reference was made to light providing energy. The teacher followed Samuel's reply with several requests for student recall of the concept identification or meaning. These responses referred to light, air, and water "getting together"; there were no references to plants making food.

CHAPTER 5

CONCLUSIONS

The key contribution of this study has been the design and implementation of a unique data collection system and the techniques for data analysis which give a researcher the capability to explore the dynamics of conceptual change. The results of this study demonstrate that the system for data collection and the methods for analysis developed for this research effort were capable of revealing the patterns necessary to investigate the dynamics of conceptual change. It has provided insights concerning the nature of conceptual change and the reasons for the difficulties encountered in teaching for conceptual change.

The results of this and other studies indicate that traditional instruction does not facilitate an appropriate reconciliation of pre-instructional knowledge with the content of instruction. Alternative conceptual systems are remarkably resistant to change by exposure to traditional instructional methods. Moreover, there appears to be evidence that these alternative conceptual systems do not facilitate the learning process.

While this study provides support for the findings of other studies (e.g., Champagne, Klopfer and Gunstone, 1982; Norman and Clement, 1981; Nussbaum and Novick, 1982b), the findings which evolved from the use of this comprehensive methodology suggest that matching instruction to the conceptual ecology of the students is both essential and difficult. The methodology (i.e., data collection as well as analysis procedures) was found to be capable of providing sufficient data to gain new insights concerning the nature of conceptual change and the reasons for the difficulties encountered in teaching for conceptual change.

The instructional sequence was based on a strategy (Knott, Lawson, Karplus and Thier, 1978) which seemed well conceived and consistent with a model of conceptual change (i.e., Posner, Strike, Hewson and Gertzog, 1982). Moreover, the teacher had the benefit of a revised guide that made the instructional sequence and its conceptual change strategy more explicit; and the observation of the classroom supported the belief that the teacher had successfully implemented it. However, the limited success of the instruction in bringing about the intended changes in student conceptions directed attention to searching for the ways in which instruction was misguided.

Discussion

This was a sequence of three case studies which followed one student's (i.e., Ben) attempt to make sense of encounters with physical phenomena during an instructional unit of learning experiences concerning photosynthesis. The student's response to incongruities between his preconceptions and the scientific content he encountered involved active construction of propositional networks whereby he used 'pieces' available to build connections for 'making sense' of classroom observations. The nature and result of this process was affected by his preconceptions as well as the features of instruction (e.g., communication and questioning patterns, interpretive frames used by the teacher and student).

There were few changes in Ben's conceptions as he experienced instruction. In each case study, the central change was an addition to Ben's conceptual framework. The data reviewed in the case studies reveals that for the most part, the instruction failed to bring about the intended changes in Ben's conceptions of the source of food for plants.

The research suggests that Ben's preconceptions influenced his interpretation of instructional content by actively competing with scientific alternatives as organizing structures for his experience of instruction and as explanations for his everyday experience. In addition, the features of instruction influenced the occurrence and direction of changes in Ben's conceptions.

The following discussion will focus upon the insights gained regarding the above points. In particular, attention will be given to the influence of preconceptions and the lack of conceptual challenge at key points in the instructional sequence, the impact of communication difficulties and the inherent ambiguity found at several key points, the important influence of tasks which expose distinctions, the lack of concept application experiences and the questioning patterns observed.

Preconceptions

The three case studies upon which this report is based provides evidence that student preconceptions are important factors in the reconciliation of internal conceptual conflicts. The preconceptions held by students continued to influence how they interpreted the natural phenomena which were observed as well as the information content which they encountered. There was evidence that alternative (i.e., naive) conceptual systems do not facilitate the learning process. These preconceptions may limit the level of "sense making" achieved by the student.

The analysis exposed that Ben's preconceptions also continued to affect how he interpreted the natural phenomena. The nature of the encounter between Ben's preconceptions and the information content at several points in the instructional sequence indicates that they (i.e., the preconceptions) were not taken into consideration.

One aspect of misconceptions (i.e., alternative frameworks) alluded to in the recent studies of conceptual change, and supported by the results of this study, is the strength of preconceptions. There seems to be support for the argument by Posner, Strike, Hewson, and Gertzog (1982) that "a new conception is unlikely to displace an old one, unless the old one encounters difficulties, and a new intelligible and initially plausible conception is available that resolves these difficulties" (p. 220). For conceptual change to occur, more is required of the teacher than simply the occasioning and structuring of content. Moreover, the student is required to go beyond the apprehension of the information content and its integration into the conceptual framework and must produce a way to deal with the incongruous situation.

Ben's conception of food for plants is that it consists of nutrients taken in from certain raw materials. There has been nothing during instruction to challenge the plausibility or fruitfulness of his conception. His encounter with alternative statements concerning food for plants (i.e., photosynthesis) doesn't in itself encourage conceptual change. This supports the contention put forth by Hewson (1981) that conceptual exchange (the process of replacing C with C') is only possible when the existing conception is found not to be plausible or fruitful and the two conceptions are irreconcilable. The elaboration or transformation of conceptual framework which is necessary for reconciliation to occur involves the generalization and re-ordering of previously assimilated concepts and principles.

<u>Ben's Conceptual Change</u>

Prior to instruction, Ben viewed food for plants as various external raw materials including light. However, Ben's preconceptions were not brought into question and they persisted. It was observed that throughout the period of instruction Ben, as well as the other students, continued to maintain their preconceptions of food for plants. A review of Ben's post-conceptions in contrast to his preconceptions reveals that he has experienced a transformation of conceptual framework. Yet that modification of conceptual structure involved what Hewson (1981) has referred to as "conceptual capture" as opposed to a "conceptual exchange." The concepts present in the preconception representation have been retained, yet with the addition of several new concepts (e.g., cotyledon, chlorophyll and photosynthesis) the relationships have not been changed. The preconception of food for plants was not displaced but was reorganized to include a mechanism for the absorption of food, a substance for making the plant green, and a process for the mixing of food sources.

Communication Difficulties

Driver and Easley (1978) have argued that student and teacher interaction is further influenced by communication difficulties brought about by the use of different interpretive frames by the teacher and student. This would seem to be supported by the level of ambiguity which was found present at several points in the transcripts. Applying the constructivist philosophy, Magoon (1977) asserts that the teacher and students are "purposive agents whose thoughts, plans, perceptions, and intentions influence their behavior and moderate the effects of behavior" (p. 652). The teacher and student engaged in social interaction in the classroom and are mutually accountable to each.

A limitation in the extent of conceptual change was the ambiguity found in the interpretative discussion concerning the function of the cotyledon. It was found that the teacher and students were proposing that the cotyledon provides food for the embryo, but the teacher was using a frame "the cotyledon is food" while the students were using a frame "the cotyledon gives/transmits food to the embryo."

Exposing Event

Support has been found for the argument that conceptual changes are influenced by the interaction of environmental factors such as teacher and student acts within the framework provided by the learning experiences and the internal reconciliation processes of the student. This was observed at several points where the teacher occasioned a discussion directed at having the students interpret the evidence gained from their experiments. It was this type of an episode in the instructional sequence which made public the alternative frameworks used by the students and provided what Nussbaum and Novick (1982) refer to as an "exposing event" (p. 4). However, while there were occasions where one could point to an exposing event, these events were seldom built upon.

Concept Application

The expectation was that the student would assimilate the propositional knowledge addressed. This merely requires the storage and retrieval from memory of the informed beliefs about content. No internal reconciliation is called for; learning is viewed as what can be referred to as progressive absolutism (Confrey, 1980). The objective of education in this case would be the reproduction of knowledge.

The nature of the discussions showed little variation between those concerned with exposing empirical evidence and those intended to develop explanatory propositions. The teacher structured the discussions in such a way as to provide as many students as possible time to present their ideas. However, these ideas were seldom challenged in a manner which would provide refutation or confirmation. A case in point is the preconceptions of food for plants which were not displaced but were reorganized to include a mechanism for the absorption of food.

Questioning Patterns

The pedagogical acts performed by the teacher influenced the student learning outcomes. The guidance provided by the teacher during classroom discussions had a profound effect upon what the students brought away from their experiences. The teacher's interpretation of the guide and her presentations influenced the student's observations and interpretations. In this sense they played a "directing" role and at times left preconceptions unchallenged.

The observation data indicates that the teacher occasioned discussions aimed at reporting the empirical observations of the students. However, as shown by the group data, the patterns thus exposed were not effectively used to influence the subjects to justify their current conceptions in the light of the encountered evidence, nor were they used to reconcile conflicting conceptions. The teacher merely provided the environment for the students to verbalize their concepts, she did not get them to juxtapose their concepts or challenge them (i.e., "What is your evidence?," "Could you explain that further?").

The questioning pattern involved the teacher posing a question and then seeking student responses in sequence. The discussions did not require the students to justify or give evidence. Neither did these discussions provide any challenge to the students' conceptualizations. It was as though if they heard all the ideas they could put it together themselves. The teacher in essence accepted the students' responses and did ask for other responses, but did not probe for insights into the students' conceptions.

This provided an atmosphere for ambiguity, the non-challenge of student interpretations and the persistence of preconceptions. Few beliefs or hypotheses offered by students were challenged for justification or juxtaposition with the conceptions of others. These tended to result in the development of inappropriate or incomplete conceptions on the part of students.

In order for the process of conceptual change to proceed, the teacher must bring to the attention of the students important distinctions which bear upon the problem to be solved. The need is for the teacher to occasion appropriate patterning activities (cf., Johnson, Rhodes and Rumery, 1975). These are activities which enable the students to impose some kind of order on the elements of study.

Implications

There are several suggestions for promoting conceptual change which emerge from these case studies. These include the consideration of student preconceptions as well as the environmental influences of classroom interaction upon Ben's conceptions and his cognitive process of "making meaning." Also of interest, are conjectures concerning avoidance of communication difficulties brought on by the use of alternative conceptions, and the importance of experimental conditions which direct student attention to significant distinctions.

The findings of this research suggest that there is a need for change in curriculum, teacher education, and the direction of science education research. The problems exposed by this study indicate that matching instruction to the conceptual ecology of the students is both essential and difficult. Students' explanatory tendencies, implicit observation theories, and preconceptions of specific topics need to be given more attention by researchers, curriculum developers, teacher educators, and teachers.

Students come to their instructional encounters with scientific concepts already having ideas, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. These alternative frameworks, in some cases resistant to change, in others flexible and with many internal inconsistencies, have a negative influence on the effectiveness of science instruction. The value of this study, however, is that it raises the awareness of the possible perspectives pupils may bring and the difficulties they may have, and hence enhances the potential for the development of more effective communication strategies.

Curriculum

The instructional materials must provide the teacher not only with an adequate strategy for promoting conceptual change, but also with an understanding of the purpose of each specific learning activity. This includes providing the teacher with information concerning the likely preconceptions of students as well as how evidence encountered by students may be used to bring about conceptual change.

Curriculum developers must be aware of predictable alternative conceptions and identify appropriate questions and other teaching moves (e.g., giving examples, probing student responses, explaining, making analogies) accordingly, and then empirically assess the effects of strategy elements on students. Curriculum development in science, and the research which supports it, must devote more attention to the structure of thought of the child. Moreover, activities in science may need to include those which enable pupils to disprove alternate interpretations, as well as affirm accepted ones. In addition, the results of this study suggests that science educators must realize that explanations do not spring clearly from the data. There must be consideration given to providing students opportunities to think through the implications of their observations and measurements made in science lessons.

Teacher Education

An important goal for any teacher education program should be the development of a conceptual change view of learning. In addition, the importance and characteristics of misconceptions should be explored along with the development of discussion skills which enable the teacher to recognize student conceptions from the responses they offer. Teachers must be aware of the alternative conceptions and the intended roles of specific questions so they can recognize indications of students' alternative conceptions and respond appropriately.

If we are to improve science education and the teaching of science, then we must have a less limited conceptualization of teaching from which we can better utilize holistic observational methodologies based upon an understanding of what teaching is (cf., Martin, 1972). Thus, having a better conception of the current framework in which "teaching" exists, as well as a normative conceptualization, we can better guide the improvement of science education.

The difficulties exposed in this study could be avoided if teachers were better prepared to listen to their pupils, understand the nature of their misconceptions and, in turn, make constructive use of this knowledge on the pupils' behalf. The private act on the part of the student of making sense of a concept with respect to previous knowledge must be accompanied by the teacher requiring justification or subjecting those private thoughts to the public scrutiny of the classroom. The development of the skills necessary in order to enable teachers to effectively apply this knowledge should be one of the primary responsibilities of every teacher education program. This study also suggests that activity by itself is not enough; it is the sense the student makes of it that matters. Teacher education programs must prepare those who will teach children to provide the environment necessary to give their students the time both individually, in groups and with their teacher to think and talk through the implications and possible explanations of what they have observed.

Educational Research

There is a need for detailed knowledge to guide curriculum development and the reformation of teacher education to accommodate a conceptual change view of learning. What is needed is an effort aimed at investigating the ways in which naive conceptions interact with instructional experiences and the application of this knowledge to the development of teaching programs. This need includes studies that will employ teaching strategies and diagnostic techniques designed to help formulate instructional systems designed to change naive theories to scientifically acceptable conceptions.

The use of the methodology developed for this study could contribute to the effort of revealing the patterns necessary to investigate the interactions between students' conceptual frameworks and classroom instruction. With the use of this methodology researchers could pursue answers to such questions as "What are the key conceptual impediments to conceptual evolution?" and "What features of instruction influence the occurrence and direction of changes in students' conceptions?"

APPENDICES

APPENDIX A

APPENDIX A.

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 3

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
3.1							
		0301	Discuss what they think is inside bean seeds.				
		0401	Obtain materials.				
		0402	Watch demonstration of how to open bean seeds.				
		0404	Describe bean parts.	20301		Bean seeds consist of these parts: two halves, a small stemlike structure and leaves.	
		0405	Describe or draw seed parts on Student p. 5.				
		0501	Watch presentation of cotyledons and embryo.	20302		The small plant like part of a bean seed is called an embryo.	
				20303		The two halves of the bean seed are called cotyledons.	
				20304	E2A	Seeds have a small, stem-like part with leaves (embryo) attached to one or two larger parts (cotyledons).	S OBS
		0502	Discuss what the seed parts do as the plant grows.				

NOTE: The propositions identified in the literal program analysis of SCIIS Communities Chapters 3-6 were organized into three types for use in analyzing students' conceptions (Smith, 1981). The three types of propositions were referred to as: empirical (E), theoretical (T) and explanatory (X). The source of each proposition was then identified as: student observations (S OBS), student hypothesis (S HYP), student inference (S INF), teacher inference (T INF), or teacher hypothesis (T HYP).

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 3 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
		0503	Discus show to determine which seed parts grow.				
		0601	Record predictions of what will happen to each seed part on student p.5.				
		0701	Clean up.				
3.2							
		0801	Optional Activity-Dissecting other seeds.				
		0802	Optional Activity-Testing for water absorption.				
		0803	Optional Activity-Soaking and drying seeds.				
		0804	Optional Activity-Heationg seeds.				
		0901	EYE 2-Immature seeds.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
4.1			The Investigation				
	1		Discuss Seed Parts and Functions				
		0301	Review seed parts and functions.				
		0302	Discuss which seed parts grow.				
		0303	Listen to purpose of investigation to find out which parts grow.				
	2		Set up Germination System				
		0401	Watch demonstration of germination system.				
		0402	Obtain materials.				
		0403	Listen to instructions for opening.				
		0404	Open soaked beans.				
		0405	Set up germination system				
		0406	Label germination system cups.				
		0407	Add water to germination systems				
	3		Measure and Record				
		0601	Measure lengths of seed parts.				
		0602	Label diagram of seed parts in the set up.				
		0603	Record measurements of seed parts. SM p.6				
		0701	Store germination system.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
4.2			Collect and Organize Data				
	4		Measure and Record				
		9901	Water germination systems.				
		9902	Measure seed parts.				
		9903	Record measurements. SM p.6				
		9904	Dry cups to prevent mold.				
	5		Demonstrate Graphing Procedure				
		0801	Listen to explanation of Growth of Seed Parts Graph.				
		0802	Watch demonstration of plotting data on growth of seed parts graph.				
	6		Graph Data in Student Manuals				
		0901	Plot seed part measurements individual graphs.				
		0902	Help/receive help in plotting data.				
		0903	Review graphing procedures.				
	7		Compile Data on Class Graph				
		1001	Record data on class growth of Seed Parts Graph.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
4.3			Average Data and Discuss				
	8		Measure and Record				
		9905	Water germination systems.				
		9906	Measure seed parts.				
		9907	Record lengths.				
	9		Average Data				
		1102	Identify the "balance point."				
		1103	Listen to explanation of analogy between the "balance" point and the average point.				
		1104	Identify the average point for another days whole seed data.				
		1105	Identify the average points for other seed parts.				
		1106	Watch connecting of points to show growth.				
	10		Discuss and Predict				
		1201	Discuss which parts grew.				
		1202	Discuss which parts grew fastest.				
		1203	Discuss future growth of parts not growing.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
4.4			Measure and Discuss				
	11		Observe and Record				
		9908	Water germination systems.				
		9909	Measure seed parts.				
		9910	Record seed part measurements on student p.6.				
		9911	Plot seed part measurements on individual graphs.				
		9912	Transfer data to class Growth of seed parts graph.				
	12		Average and Discuss				
		9913	Determine average points.				
		9914	Watch connection of points.				
		9915	Discuss which parts grew.				
		9916	Discuss which parts grew fastest.				
		9917	Discuss future growth of parts not growing.				
4.5			Measure and Discuss				
	13		Observe and Record				
		9918	Water germination systems.				
		9919	Measure seed parts.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	13		Observe and Record (continued)				
		9920	Record seed part measurements on student p.6.				
		9921	Plot meausrements on individual graphs.				
		9922	Transfer data to class growth of seed parts graph.				
	14		Average and Discuss				
		9923	Determine average points.				
		9924	Watch connection of points.				
		9925	Discuss which parts grew.				
		9926	Discuss which parts grew fastest.				
		9927	Discuss future growth of parts growing.				
4.6			Measure and Discuss				
	15		Observe and Record				
		9928	Water germination systems.				
		9929	Measure seed parts.				
		9930	Record seed part measurements on student p.6.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	15		Observe and Record (continued)				
		9931	Plot measurements on individual graphs.				
		9932	Transfer data to class Growth of Seed Parts Graph.				
	16		Average and Discuss				
		9933	Determine average points.				
		9934	Watch connection of points.				
		9935	Discuss which parts grew.				
		9936	Disucss which parts grew fastest.				
		9937	Discuss future growth of parts not growing.				
4.7			Measure and Record				
	17		Observe and Record				
		9938	Water germination systems.				
		9939	Measure seed parts.				
		9940	Record seed parts measurements on student p.6.				
		9941	Plot measurements on individual graphs.				
		9942	Transfer data to class graph.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	18		Average Data				
		9943	Determine average points.				
		9944	Watch connection of points.				
4.8		Interpretation of Results					
	19		Review Results				
		1204	Discuss which seed parts and combinations grew and did not grow.	20403	E3A	Bean seed embryos not attached to cotyledons don't grow.	S OBS
				20404	E3A	Bean seed cotyledons without embryos attached do not grow.	S OBS
				20405	E5A	Bean seed cotyledons do not grow as the attached embryo grows.	S OBS
				20406	E4A	The embryo is the part of the seed that grows.	S OBS
				20407	E3A	Seed embryos grow only if attached to a cotyledon.	S OBS
				20408	E5A	Bean seed cotyledons shrink as the attached embryo grows.	S OBS
	20		Discuss Functions of Seed Parts				
		1205	Discuss reasons for parts and combinations growing or not growing.	20409	T2A	The cotyledons are food for the embryo of a seed.	S INF

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 4 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	20		Discuss Functions of Seed Parts (continued)				
		1206	Compare growth of whole seed and embryo with one cotyledon.	20401	E3A	Bean embryos with one cotyledon attached grow.	S OBS
				20402	E3A	Whole bean seeds (embryo with 2 cotyledons) grow.	S OBS
				20411		Whole bean seeds (with 2 cotyledons) grow better than embryos with only one cotyledon.$	S OBS
		1207	Discuss functions of embryo and cotyledon.				
		1208	Predict effects of large and small cotyledon.				
4.9			Clean-up and Optional Activities				
	21		Clean-up				
		1301	Clean up.				
	22		Optional Activities				
		1401	Optional Activity - Plants without soil.				
		1402	Optional Activity - Cotyledon systems.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
5.1			The Investigation				
	1		Discuss the Question				
		0501	Discuss whether plants need light to begin to grow.				
	2		Set up the Experiment				
		0601	Plant grass seed.				
		0602	Decide teams for light & dark.				
		0603	Label cups.				
		0604	Place cups on trays for storage.				
5.2			The Measurements				
	3a		Observe and Record				
		0701	Water the plants.				
		0702	Fill in key graph (SM8).				
		0703	Measure height of tallest plant.				
		0704	Determine average height of plants.				
		0705	Graph heights of plants (SM8).				
		0706	Exchange plants.				
		0707	Measure others plants.				
		0708	Copy others data.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
5.3			Measure and Discuss				
	3b		Observe and Record				
		9901	Water the plants.				
		9902	Measure height of tallest plant.				
		9903	Determine average height of plants.				
		9904	Graph height of plants (SM8).				
	4		Discuss Results				
		0709	Discuss why plants in dark are growing so well.	20501	E6A	Grass plants begin to grow from seeds in the dark.	S OBS
				20502	E6A	Grass plants begin to grow from from seeds in the light.	S OBS
				20505	X2	Grass plants begin to grow in the dark because the cotyledons provide food.	S HYP
5.4			Measure, Observe, and Switch Half of the Setups				
	3c		Observe and Record				
		9905	Water the plants.				
		9906	Measure height of tallest plant.				
		9907	Determine average height of plants.				
		9908	Graph height of plants.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	3c		Observe and Record (continued)				
		0801	Observe colors of plants.	20503	E7A	Grass plants growing in the dark turn yellow.	S OBS
				20504	E7A	Grass plants growing in the light turn green.	S OBS
	5		Discuss how to Reverse Colors				
		0802	Gather for a discussion.				
		0803	Discuss which plants will survive better and why.				
		0804	Discuss how to reverse colors.				
	6		Switch Half the Setups				
		0805	Label and place half the cups in the opposite condition.				
5.5			Measure and Record				
	7a		Observe Grass in Light and Dark and Record Heights				
		9909	Water the plants.				
		9910	Measure height of tallest.				
		9911	Determine average height of plants.				
		9912	Graph height of plants (SM8).				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	7a		Observe Grass in Light and Dark and Record Heights (continued)				
		9913	Observe condition and color of plants				
5.6			Measure and Record				
	7b		Observe Grass in Light and Dark and Record Heights				
		9914	Water the plants.				
		9915	Measure height of tallest.				
		9916	Determine average height of plants.				
		9917	Graph height of plants (SM8).				
		9918	Observe condition and color of plants	20506	E7A	Yellow grass plants moved from the dark to the light turn green in a few days.	S OBS
				20507	E7A	Green grass plants moved from the light to the dark turn yellow in a few days.	S OBS
5.7			Measure and Record				
	7c		Observe Grass in Light and Dark and Record Heights				
		9919	Water the plants.				
		9920	Measure height of tallest.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	7c		Observe Grass in Light and Dark and Record Heights (continued)				
		9921	Determine average height of plants.				
		9922	Graph height of plants (SM8).				
		9923	Observe condition amd color of plants.				
5.8			Measure and Record				
	7 d		Observe Grass in Light and Dark and Record Heights				
		9924	Water the plants.				
		9925	Measure height of tallest.				
		9926	Determine average height of plants.				
		9927	Graph height of plants (SM8).				
		9928	Observe condition and color of plants.				
5.9			Measure and Record				
	7e		Observe Grass in Light and Dark and Record Heights				
		9929	Water the plants.				
		9930	Measure height of tallest.				
		9931	Determine average height of plants.				
		9932	Graph height of plants (SM8).				
		9933	Observe condition and color of plants.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
5.10			Conclude the Investigation				
	7f		Observe Grass in Light and Dark Record Heights				
		9934	Water the plants.				
		9935	Measure height of tallest.				
		9936	Determine average height of plants.				
		9937	Graph height of plants (SM8).				
		9938	Observe condition and color of plants.	20508	E9A	Grass plants grown in the dark die after several days.	.S OBS
				20509		Grass plants moved to the dark die after several days.	
	8		Interpret Results				
		0901	Summarize results on SM8.	20510	E9A	Grass plants grown in the light stay alive.	S OBS
				20511		Grass plants moved to the light stay alive.	
		1001	Describe results for each setup.	20512	T5A	Plants do not get their food from the soil.	S INF
		1002	Discuss roles of light and cotyledon.				
		1003	Discuss where plants get their food.	20513	T1A	Plants need food.	S INF
				20514	T1A	Plants are like animals in their need for food.	S INF
				20515	T3A	Plants make their own food in the light.	S INF

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	9		Invent Photosynthesis				
		1004	Listen to explanation of photosynthesis.	20516		Plants can grow for a long time without soil if they have air and water.	
				20517		When sunlight reaches a plant, the plant takes in some of the suns energy.	
				20518	T4A	Plants use the suns energy with air and water for making food.	T INF
				20519		The name of plants food making process is photosyntheis.	
				20520		Photo means light.	
				20521		Synthesis means putting together.	
		1005	Discuss the evidence and photosynthesis.	20522	X3 X6	Grass grown in the dark dieswhen it used up food in the cotyledon because there is no light for it to use to make food.	T HYP
				20523	X3	Plants growing in the light continue to live and grow because they make their own food.	T HYP
5.11			Assess Learning				
	10		Brain Teaser				
		1101	Write answers to brain teaser (SM9).				
		1102	Discuss answers to brain teaser.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 5 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
5.12			Optional Activities				
	11		Optional Activities				
		1201	Plant food.				
		1202	Plants without air.				
		1203	How much light?				
		1204	Plants in artificial light.				
	12		Clean-up				
		1301	Clean-up				
	13		Extending Your Experiences				
		1401	Is soil needed for plant growth?				
		1402	Does "plant food" feed plants?				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
6.1							
	1		Plant Bean Seeds				
		0301	Watch demonstration of assembly of planter system.				
		0302	Plant bean seeds.				
		0303	Label planter systems.				
		0304	Water planter systems.				
		0305	Watch demonstration of removal of excess water.				
		0401	Suggest area to store plants.				
		0402	Store plants in a dark area.				
		9901	Water plants.				
		9902	Support plants with twistems.				
6.2			The Investigation				
	2		Discuss the Question				
		0403	Review results of earlier experiments.				
		0404	Discuss predictions of growth of plants with cotyledons removed.				
		0501	Record predictions of growth of plants with cotyledons removed.				
		0502	Record explanation of predictions.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	3		Set up the Experiment				
		0601	Prepare set up of plants with and without cotyledons.				
		0602	Set extra plants aside for other use.				
		0603	Discxard extra plants.				
		0701	Label planter cups light or dark.				
	4		Make and Record Initial Measurements				
		0702	Measure height of plants.				
		0703	Store plants in light and dark.				
		0704	Record measurements on p.11.				
	5		Complete the Data on Class Graphs				
		0705	Fill in color key for plant growth graphs.				
		0706	Transfer data to plant growth graphs.				
		0801	Transfer data to class plant growth graphs.				
6.3			Measure and Record				
	6 a		Observe and Record				
		9903	Measure heights of plants.				
		9904	Record measurements on p.11.				
		9905	Graph data on p.12				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	6a		Observe and Record (continued)				
		9906	Transfer data to class plant growth graphs.				
		9907	Determine average height values.				
		9908	Watch connection of data points.				
		9909	Compare plant growth under the different conditions.				
6.4			Measure and Record				
	6b		Observe and Record				
		9910	Measure heights of plants.				
		9911	Record measurements on p.11.				
		9912	Graph data on p.12				
		9913	Transfer data to class plant growth graphs.				
		9914	Determine average height values.				
		9915	Watch connection of data points.				
		9916	Compare plant growth under the different conditions.				
6.5			Measure and Record				
	6c		Observe and Record				
		9917	Measure heights of plants.				
		9918	Record measurements on p.11.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
	6c		Observe and Record (continued)				
		9919	Graph data on p.12.				
		9920	Transfer data to class graph.				
		9921	Determine average height values.				
		9922	Predict next average height values				
6.6			Measure and Record				
		9923	Measure heights of plants.				
		9924	Record measurements on p.11				
		9925	Graph data on p.12				
		9926	Transfer data to class graph.				
		9927	Determine average height values.				
		9928	Predict next average height values.				
6.7							
		0908	Discuss length values to be assigned to wilted plants.	20605	E10A	Bean plants without cotyledons wilt and die when left in the dark for several days.	S OBS
				20611	E9A	Bean plants in the dark die after several days.	S OBS
		9929	Measure heights of plants.				
		9930	Record measurements on p.11.				
		9931	Graph data on p.12				
		9932	Transfer data to class graph.				
		9933	Detetrmine average height values.				
		9934	Predict next average height values.				

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
6.7 (continued)							
		1001	Record inferred function of cotyledon on p. 11.	20601	E12A	Plants without cotyledons do not grow well in the dark.	S OBS
				20602	E11A	Plants with cotyledons grow well in the dark.	S OBS
				20603	E10A E12A	In the dark, plants with cotyledons grow better than those without cotyledons.	S OBS
				20604	E11A	In the light, plants without cotyledons grow about as well as those with them.	S OBS
6.8			Measure and Record				
		9935	Measure heights of plants.				
		9936	Record measurements on p. 11.				
		9937	Graph data on p. 12.				
		9938	Transfer data to class graph.				
		9939	Determine average height values.				
		9940	Predict next average height values.				
		1101	Compare cotyledons with original appearance.	20609		Cotyledons shrivel and drop off bean plants after two or three weeks.	
				20610		Bean plant cotyledons shrivele as the plants get bigger.	
		1102	Discuss what happened to the plants. as the cotyledons shriveled.	20612		The graph line for the plants in the dark levels off or drops down after several days.	

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
6.9			Measure and Record				
		9941	Measure heights of plants.				
		9942	Record measurements on p. 11.				
		9943	Graph data on p. 12.				
		9944	Transfer data to class graph.				
		9945	Determine average height values.				
		1201	Discuss results of plant growth under different conditions.	20606	E10A	In the dark, bean plants with cotyledons grow taller than those withou cotyledons.	S OBS
				20607	E12A	There is little difference in in height of bean plants with and without cotyledons grown in the light.	S OBS
				20613		Plants in the light eventually grow better than those in the dark.	
				20615	X6	When the cotyledons fall off a plant grown in the light, the plant still survives because it makes its own food.	T HYP
				20616	X6	Plants grown in the dark are unable to photosynthesize and thus die after the food stored in the cotyledons is exhausted.	T HYP
		1202	Discuss functions of cotyledons and light for plants.	20608	T2A	Cotyledons provide food for young plants to grow.	T INF
				20614	T6A	Plants need light to grow after their stored food is used up.	T INF

APPENDIX A. (continued)

ORGANIZATION AND PROPOSITIONAL KNOWLEDGE OF CHAPTERS 3-6

Chapter 6 (continued)

LESSON	ACT	TASK	DESCRIPTION	PROPOSITION NO.	PROPOSITION TYPE	PROPOSITION	SOURCE
6.9			Measure and Record (continued)				
		1203	Attend to explanation of experiment.				
		1301	Predict surrvival of plants in a cave.				
		1302	Explain prediction.				
6.10			Optional Activities				
		1401	Optional Activity-Dandelions.				
		1402	Optional ACTIVITY-coleus or Geranuim.				
		1501	Clean-up.				
		1601	EYE 5-Where are the cotyledons.				
		1602	EYE 6-Peices of cotyledons.				

APPENDIX B

Psychomodeling Instrument

Name____________________

PRODUCERS TEST

Form D

Edward L. Smith
Charles W. Anderson
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Institute for Research on Teaching
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January 22, 1982

Part I

1. Do plants need food?____________________

   Why or why not?____

2. Describe what food is for plants?

3. Do plants need light?____________________

   Why or why not?____

4. If you opened a lima bean seed what would it look like? You may draw a picture.

   Label the picture if you can.

5. A man wanted to have an early garden. He planted some tomato seeds in small boxes. He kept the boxes in a closet where it was warm and dark. He watered them whenever the soil started to get dry.

   What do you think happened to the seeds?__________________________

   Why would this happen?__________________________

Part II

Choose <u>one</u> answer for each question. Circle the letter for the answer you choose.

1. Most plants get food

    a. from soil.
    b. from air.
    c. from water.
    d. by making it themselves.
    e. I don't know.

2. To begin growing from seeds, plants do <u>not</u> need

    a. water.
    b. light.
    c. warm temperature.
    d. the part of the seed called the cotyledon.
    e. I don't know.

3. Seeds planted in the dark would

    a. grow the same as seeds planted in the light.
    b. grow shorter than seeds planted in the light.
    c. grow taller than seeds in the light and then die.
    d. not grow at all.
    e. I don't know.

4. When do plants make their own food?

    a. never.
    b. in the light.
    c. in the dark.
    d. in the light and in the dark.
    e. I don't know.

5. Which living things <u>take in</u> their food?

    a. only animals.
    b. only plants.
    c. both plants and animals.
    d. neither plants nor animals.
    e. I don't know.

6. Which living things make their own food

    a. only animals.
    b. only plants.
    c. both plants and animals.
    d. neither plants nor animals.
    e. I don't know.

7. For plants food means

    a. water.
    b. water, soil, air, and light.
    c. water, air, and light.
    d. fertilizer and minerals.
    e. something they make.
    f. I don't know.

8. When do animals <u>make</u> their own food?

    a. never.
    b. in the light.
    c. in the dark.
    d. in the light and in the dark.
    e. I don't know.

9. When someone says that plants make their own food, they probably mean that

    a. plants make materials that are then used for growth and energy.
    b. plants make leaves, roots, and stems from materials like water and air.
    c. plants use water and air for energy.
    d. I don't know.

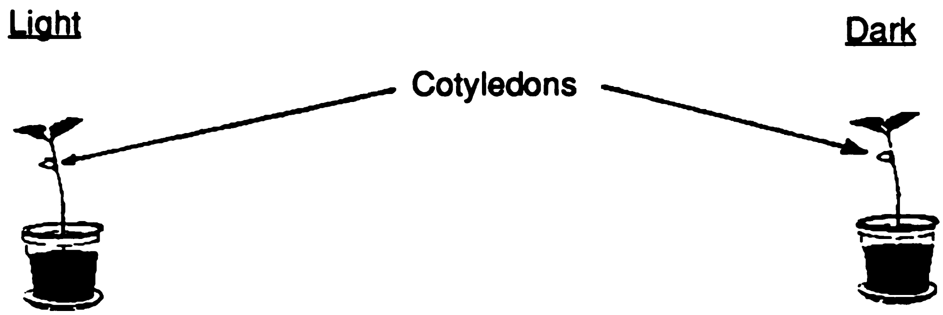
Part III

Write T by the number of the statements you think are true. Write an F by those you think are false. Write ? if you do not know whether it is true or false.

1. _______ Seeds contain food for new plants to use to begin growing.
2. _______ Seeds need light for new plants to begin growing.
3. _______ Plants use food from the soil to begin growing from seeds.
4. _______ Some seeds can be used as food for animals.
5. _______ Green peas that you eat are seeds.
6. _______ Plants use water as food to begin growing.
7. _______ The whole seed gets bigger as a new plant starts to grow.
8. _______ Part of a seed gets bigger and another part gets smaller as a new plant starts to grow.
9. _______ Seeds do not have any value as food.
10. _______ Plants must have food to live.
11. _______ Animals must have food to live.
12. _______ Plants can get energy from the sun.
13. _______ Animals can get energy from the sun.
14. _______ Plants get food energy from the soil.
15. _______ Animals get food energy from the food they eat.

An Experiment

John planted two bean seeds in good soil and watered them. When the plants were still very small, he put one plant in the sunlight and one plant in the dark.



Write T, F, or ? for each statement about this experiment.

16.______ The plant in the light will live longer than the plant in the dark.

17.______ The plant in the dark will not grow any more.

18.______ The plant in the light uses food from the cotyledons.

19.______ The plant in the dark uses food from the cotyledons.

20.______ The plant in the light makes its own food.

21.______ The plant in the dark makes its own food.

22.______ The plant in the light uses food from the soil.

23.______ The plant in the dark uses food from the soil.

24.______ If the cotyledons are cut off, then the plant in the light will stop growing. Explain your answer.

____

____

____

25. ______ If the cotyledons are cut off, then the plant in the dark will stop growing. Explain your answer.

____

____

____

____

APPENDIX C

Data Collection Instruments

CONCEPTUAL CHANGE PROJECT

DATE ________ TEACHER ______ GRADE ______ CURRICULUM ____________ PAGE ____ OF ____

CLASSROOM DESCRIPTION				
STUDENT TASK IDENTIFICATION	TEACHER ACTS	CLASSROOM (MILIEU)	TIME	TARGET GROUP

CONCEPTUAL CHANGE PROJECT

Date ____________ Teacher ____________ Program ________________ Lesson # ________________ Reviewer ____________

Time	Activity Task #	Activity Task	Comments	Propostional Knowledge Addressed		
				Frame	Source	Comments

Lesson Summary:

CONCEPTUAL CHANGE PROJECT

DATE ____________ TASK # ____________ RELATED PROGRAM TASK ____________

TASK DESCRIPTOR ____

TAPE #	FRAME	NARRATIVE

APPENDIX D

APPENDIX D.

PROPOSITIONAL FRAMES FOR SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS		MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
		VALID (A-J)	ALTERNATIVE (K-U)	
A	Seeds (can/cannot) be food for animals and seeds (can/cannot) be sources of new plants	A can be sources of new plants B can be food C can be eaten by people D are healthful E taste good F peas are seeds	K are not sources L are not food M cannot be eaten by people N are harmful O don't taste good P peas are not thought of as seeds	1 can, can 2 cannot or cannot
B	Seeds (do/do not) have parts including ( ).	A small, plant-like part B large part or "halves" C Embryo is attached D "embryo" label E "cotyledon" label F Seed coat G more than one part	K no small plant-like part L no large part or "halves" M Pods are seeds N no or incorrect label P no or incorrect label Q embryo incorrectly attached R only one part	1 do, stem-like part with leaves/embryo and large part/ halves/cotyledon 2 do, large part(s) only 3 Pods are seeds
C	The embryo and cotyledon (do/do not) grow when separate and (do/do not) grow when attached.	A do not, no reference B no reference, do	K do, no reference L no reference, do not	1 do not, do 2 do, do
D	The (seed part) (does/does not) grow into the new plant.	A embryo gets bigger B embryo, does C whole seed does not get bigger.	K embryo does not grow L embryo, does not M whole seed gets bigger N whole seed, does	1 embryo, does (same as DB) 2 whole seed, does (same as DN)

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS VALID (A-J)	COMPONENT PROPOSITIONS ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
D	The (seed part) (does/does not) grow into the new plant. (continued)			8 inconsistent
E	The cotyledon (change size) as the embryo/plant grows.		L gets bigger	1 shrivels/gets smaller 2 does not shrivel 8 inconsistent
F	Plants without the cotyledons continue to grow in (condition: light/dark) because (proposition).		K light, they have food W that's what happened	1 only in light, plants make their own food only in light 2 in neither light nor dark, cotyledon provides food for plant. 3 in neither light nor dark, removing the cotyledon injures the plant 4 only in light plants have food only in light 5 only in light, plants need light to grow 6 in light or dark, get food from soil

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS VALID (A-J)	COMPONENT PROPOSITIONS ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
G	Plants (and animals) (do/do not) need food to (function).	A do, no reference B do, live C do, grow E do, health F do, because they are alive G do, to make chlorophyll G do, energy H do, build bodies	K do not, no reference L do not, live M do not, grow W do, doesn't know	1 do, live/grow 2 do not, healthy 3 do, grow 4 do not, 9 doesn't know
H	The cotyledon (does/does not) provide food for the young plant in (condition: light/dark).	A does, no reference B does, light C does, dark D (Seed) does,	K does not, no reference L does not, light M does not, dark N (Seed) does not O Removing the cotyledon injures the plant. P does (collects/transmits) food, no reference	1 does, in light and dark (or just does) 2 does, in dark only 3 does, in light only 4 does not, (light or dark)
I	Plants (do/do not) make food.	A recognition item subscore (do) B production item subscore (do)		1 do 2 do not 8 ? meaning (animals do)
J	The embryo and cotyledon (do/do not) grow when attached and (do/do not) grow when separate because (proposition).	none defined		1 do, do not, the cotyledon provides food for the plant/embryo

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS: VALID (A-J)	COMPONENT PROPOSITIONS: ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
K	Plants (do/do not) make their own food in (condition: light/dark).	B do, light C do not, dark	K do not, no reference L do not, light M do, dark N Sun/light makes/gives food for the plant	1 do, only in light 2 do, only in dark 3 do, in light and dark 4 do not
L	Plants (do/do not) use (materials) to make food.	A do, light/light energy, no reference to making food B do, light/light energy C do, air D do, water E do, photosynthesis	K do not, light, no refer ence to make food M do not, light/energy N do not, air O do not, water	1 do; light, water air/CO2
M	Plants (do/do not) take in their food from (location).	A do not, soil B do not, water C do not, air D do not, no reference	K do, soil L do, water M do, air N do, no reference O do, light	1 do not, <any> 2 do, <any> 8 ? meaning (animals do not)
N	Plants need (material,condition) to live/grow.	A not soil B water C (see Z) D air E carbon dioxide F oxygen G minerals H cotyledon/seed I warmth J energy	K soil L fertilizer M care, affection N (see G2 & G3) O not water S not warmth	1 (cotyledon or food) and light and not soil and not fertilizer 2 light, air or CO2, water and not soil and not fertilizer 3 water, air, soil and light and not fertilizer

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS: VALID (A-J)	COMPONENT PROPOSITIONS: ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
O	Food for plants (is/is not) raw (materials)	A is not, water B is not, fertilizer C is not, minerals D is not, air E is not, light F is not soil G is not, CO^2 H is not, O^2 I cotyledon J something made	K is, water L is, fertilizer M is, minerals O is, light P is, soil Q is, CO^2 R plants "need" ... or shelter, care, etc. S is, photosynthesis T is, air U is, chlorophylll	1 water, fertilizer soil, light, minerals, air, vitamins, nutrients 2 only water, is 3 only water, CO^2/air, light 4 other raw materials 5 only fertilizer, soil, minerals
P	Plants (do/do not) begin to grow from seeds in (condition: light/dark).	A do, light B do, dark	K do not, light L green, dark	1 green, only in light 2 green, light and dark
Q	Plants are (property: color) in (condition: light/dark).	A green, light B not green, dark	K not green, light L green, dark	1 green, only in light 2 green, light and dark
R	Plants in the dark begin to grow (comparative: height)	none defined		1 taller than as plants in the light. 3 shorter 4 same height
S	Plants (do/do not) continue to grow in (condition: light/dark).	A do, light B do not, dark	K do not, light L do, dark O do, dark but are not healthy	1 do, only in light 2 do, in light or dark

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS VALID (A-J)	COMPONENT PROPOSITIONS ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
T	Plants with cotyledons (do/do not) continue to grow in (conditin: light/dark).	A do, no reference B do, light C do, dark	K do not, no reference L do not, light M do not, dark	1 in light or dark 2 only in light
U	Plants without cotyledons (do/do not) continue to grow in (condition: light/dark).	A do, light B do not, dark	K do not, light L do, dark X doesn't know in light U doesn't know in dark	1 only in light 2 neither in light nor dark 3 light and dark
V	Plants with cotyledons (do/do not) continue to live in (condition: light/dark) because (proposition).	A do, no reference, cotyledon provides food B do, dark, C do, light,		1 in light or dark plants get food from the cotyledon 2 light and dark, food from soil
W	Plants (do/ do not) begin to grow from seeds in (condition: light/dark) because (proposition).	A do, light, cotyledon provides food B do, dark, cotyledon provides food C do, dark, no reference		1 do, light or dark, young plants get food from the cotyledon/seed 2 light or dark, young plants get food from the soil. 3 light only, young plants need light to grow. 4 light only, need light as food
X	Plants (do/do not) need light to begin to grow and (do/do not) need light to continue to grow.	A do (unqualified) B do not, no reference C no reference, do	K do not (unqualified) L do, no reference M no reference, do not	1 do not, do 2 do not, do not 3 do, do

APPENDIX D. (continued)

PROPOSITIONAL FRAMES FOR THE SCIIS PRODUCERS UNIT ANALYSIS

f	PROPOSITION FRAME	COMPONENT PROPOSITIONS: VALID (A-J)	COMPONENT PROPOSITIONS: ALTERNATIVE (K-U)	MULTI-PROPOSITIONS (1=goal proposition) (9=I don't know)
Y	Plants continue to live in (condition: light/dark) because (proposition).	none defined		1 only in light, plants need ight to make food 2 light or dark, plants get food from soil 3 only in light, plants need light to grow 4 only in light, plants need light 5 only in light, plant need light to make chlorophyll 6 only in light, need light as food
Z	Plants (do/do not) need light to (function).	A do, live B do, grow C do, make food/PHS D do, be healthy E do, be green F do, for photosynthesis G do, for energy H do, for food I do, to make chlorophyll	K do not, live L do not, grow M do not, make food N do not, be healthy O do not, be green P do not, for energy Q do, to make PHS	1 do, make food for energy 2 do, live/grow 3 do, be healthy 4 do not, 5 do, for food 8 do, doesn't know why 9 doesn't know
B%	Photosynthesis is ( ).	A process for making food	K water, air, and light getting together L water and air getting together	1 a process for making food using water, air, and light

APPENDIX E

APPENDIX E.

PROPOSITIONAL FRAMES AFFIRMED DURING INSTRUCTION

f PROPOSITION FRAME	LESSONS																					
	3.1	4.1	4.2	4.3	4.4	4.5	4.7	5.1	5.2	5.3	5.4	5.5	6.1	5.6	5.10	6.2	6.3	6.4	6.5	6.6	6.7	6.9
A Seeds (can/cannot) be food for animals and seeds (can/cannot) be sources of new plants.																						
B Seeds (do/do not) have parts including ( ).	12	1							1													
C The embryo and cotyledon (do/do not) grow when separate and (do/do not) grow when attached.				B	1	B 1	1 A									B						
D The (seed part) (does/does not) grow into the new plants.	1			A		N	12		1													
E The cotyledon (change size) as the embryo/plant grows.					A		A3		A		1				12					12		
F Plants without the cotyledon continue to grow in (condition: light/dark) because (proposition).																					1	

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX E. (continued)

PROPOSITIONAL FRAMES AFFIRMED DURING INSTRUCTION

f	PROPOSITION FRAME	LESSONS																					
		3.1	4.1	4.2	4.3	4.4	4.5	4.7	5.1	5.2	5.3	5.4	5.5	6.1	5.6	5.10	6.2	6.3	6.4	6.5	6.6	6.7	6.9
G	Plants (and animals) (do/do not) need food to (function).											1				1 G A							B2
H	The cotyledon (does/does not) provide food for the young plant in (condition: light/ dark).	A				A	A2	A5 K2		A5	C	C	C3	C2		A4 C P6					A		
I	Plants (do/do not) make food.																						
J	The embryo and cotyledon (do/ do not) grow when attached and (do/do not) grow when separate because (proposition).																						
K	Plants (do/do not) make their own food in (condition: light/ dark).												B										
L	Plants (do/do not) use (materials) to make food.												A			A 1							

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX E. (continued)

PROPOSITIONAL FRAMES AFFIRMED DURING INSTRUCTION

f	PROPOSITION FRAME	LESSONS																					
		3.1	4.1	4.2	4.3	4.4	4.5	4.7	5.1	5.2	5.3	5.4	5.5	6.1	5.6	5.10	6.2	6.3	6.4	6.5	6.6	6.7	6.9
M	Plants (do/do not) take in their food from (location).											2 L3 K				L3 K O4 M							
N	Plants need (material, condition) to live/grow.											A C4				2		H					
O	Food for plants (is/is not) raw (materials).						L		L K O	K		L K	K3 O3 I3 P			K I4	J	I	O I J		K O I J T	I P J F M	K I J2 F M
P	Plants (do/do not)) begin to grow from seeds in (condition: light/dark).													A			1						

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX E. (continued)

PROPOSITIONAL FRAMES AFFIRMED DURING INSTRUCTION

f	PROPOSITION FRAME	LESSONS																					
		3.1	4.1	4.2	4.3	4.4	4.5	4.7	5.1	5.2	5.3	5.4	5.5	6.1	5.6	5.10	6.2	6.3	6.4	6.5	6.6	6.7	6.9
Q	Plants are (property: color) in (condition: light/dark).											14	1 B2		1 B	1							
R	Plants in the dark begin to grow (comparative: height).										15	13		1									
S	Plants (do/do not) continue to grow in (condition: light/dark).								L			14 O			B	1 B	B					B	
T	Plants with cotyledons (do/do not) continue to grow in (condition: light/dark).																	13 B M	2 C	C2		B C2	
U	Plants without cotyledons (do/do not) continue to grow in (condition: light/dark).																A L B2	A2 L B 1 K	A B	B2		A L	

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX E. (continued)

PROPOSITIONAL FRAMES AFFIRMED DURING INSTRUCTION

f	PROPOSITION FRAME	LESSONS																					
		3.1	4.1	4.2	4.3	4.4	4.5	4.7	5.1	5.2	5.3	5.4	5.5	6.1	5.6	5.10	6.2	6.3	6.4	6.5	6.6	6.7	6.9
V	Plants with cotyledons (do/do not) continue to live in (condition: light/dark) because (proposition).																	B	B2 A C				
W	Plants (do/do not) begin to grow from seeds in (condition: light/dark) because (proposition).											B	B										
X	Plants (do/do not) need light to begin to grow and (do/do not) need light to continue to grow.								C M													C	C2 M
Y	Plants continue to live in (condition: light/dark) because (proposition).																						
Z	Plants (do/do not) need light to (function).											G 23 E2	E4 1 H I			G E H C2 D3		2				B	3 A
B%	Photosynthesis is ( ).															14 K							

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F

APPENDIX F.

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f PROPOSITION FRAME	LESSONS																	
	Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
A Seeds (can/cannot) be food for animals and seeds (can/cannot) be sources of new plants.	1 B2 9																	12 B2 F
B Seeds (do/do not) have parts including ( ).	9	9			9													1 A B C N P
C The embryo and cotyledon (do/do not) grow when separate and (do/do not) grow when attached.					12							B						
D The (seed part) (does/does not) grow into the new plants.					B		1											1
E The cotyledon (change size) as the embryo/plant grows.	9		A															1
F Plants without the cotyledon continue to grow in (condition: light/dark) because (proposition).	X												K			1		O Y

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F. (continued)

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f	PROPOSITION FRAME	LESSONS																	
		Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
G	Plants (and animals) (do/do not) need food to (function).	13 A B C	1 C						12			G		1					13 A B C
H	The cotyledon (does/does not) provide food for the young plant in (condition: light/ dark).	1 9 C2 D	4			A B P2		A				P						C	13 C A B D
I	Plants (do/do not) make food.	1 82 9												1			1		1 23
J	The embryo and cotyledon (do/ do not) grow when attached and (do/do not) grow when separate because (proposition).					1													
K	Plants (do/do not) make their own food in (condition: light/ dark).	2 9 L M															1		O C L

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F. (continued)

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f	PROPOSITION FRAME	LESSONS																
		Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
L	Plants (do/do not) use (materials) to make food.																		
M	Plants (do/do not) take in their food from (location).	23 92 K3	K4 L3 O2 N						2 L		K L			K				K2	23 K2 1 8 O A M
N	Plants need (material, condition) to live/grow.	9	B L									2		B K2 G I				B K G2 D2	

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F. (continued)

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f PROPOSITION FRAME	LESSONS																	
	Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
O Food for plants (is/is not) raw (materials).	1 3 92 A K O T	O L 5		L	K2	K O L		K L	O	O		J	M U	I		J I P	K O T L M I F	12 42 A K2 O2 T2 L J I P
P Plants (do/do not)) begin to grow from seeds in (condition: light/ dark).	92									1		A B						12 B2
Q Plants are (property: color) in (condition: light/dark).									B	B2 1			A				B A	
R Plants in the dark begin to grow (comparative: height).	9																A	1

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F. (continued)

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f	PROPOSITION FRAME	LESSONS																
		Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
S	Plants (do/do not) continue to grow in (condition: light/dark).	93	2								2 A L		B	B 1				1	A B3 13
T	Plants with cotyledons (do/do not) continue to grow in (condition: light/dark).	9												C	B M	C	C	B	C 1
U	Plants without cotyledons (do/ do not) continue to grow in (condition: light/dark).	9 B X											1	A	1	B	1	A	A O
V	Plants with cotyledons (do/do not) continue to live in (condition: light/dark) because (proposition).	O												B				B	2
W	Plants (do/do not) begin to grow from seeds in (condition: light/ dark) because (proposition).										A								O

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

APPENDIX F. (continued)

PROPOSITIONAL FRAMES AFFIRMED BY BEN

f	PROPOSITION FRAME	LESSONS																
		Pre	CI1	4.4	4.5	CI2	5.1	5.2	5.4	5.5	CI3	5.10	6.2	CI4	6.3	6.4	6.7	CI6	Pos
X	Plants (do/do not) need light to begin to grow and (do/do not) need light to continue to grow.	3 9 A B									M			C					3 A B2 1
Y	Plants continue to live in (condition: light/dark) because (proposition).										5								3
Z	Plants (do/do not) need light to (function).	2 B	2						E	E H	B E2 I5	H		22 B E I2				E I3 A F2 G	22 A
B%	Photosynthesis is ( ).																	K L	

NOTE: Letters represent propositional frame alternatives. Numbers represent number of times the propostion was asserted.

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